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DEVELOPMENT OF THE PROFILE OF EQUILIBRIUM OF THE SUBAQUEOUS SHORE TERRACE.

THE profile of a shore as seen at any one time is a compromise between two forms. One of these is the form which it possessed when the water assumed its present level; from this form it is continually departing. The other is the form which the water is striving to give to it; toward this form it is continually tending. There is a profile of equilibrium which the water would ultimately impart, if allowed to carry its work to completion. The continual change of shore line and the supply of new drift are everchanging conditions with which no *fixed* form can be in equilibrium. There are, however, certain adjustments of current, slope and load which, when once attained, are maintained with some constancy. The form involved in these adjustments is commonly known as the *profile of equilibrium*. When this profile has once been assumed the entire form may slowly shift its position toward or from the land, but its slope will change little or not at all. It may be compared to a stream channel which has reached grade but not base level.

The force which the water exerts is derived ultimately from the wind. The immediate agencies in the work are waves and currents. It will be convenient to consider these first as acting independently of the wind which caused them, and second, as acting under its continuous influence. It is also desirable to

consider waves first in their free forms, while meeting no resistance and hence doing no external work. This condition is found in deep water. The various ways in which the bottom or shore may offer resistance and be subject to work may then be discussed.

WAVES IN WATER OF INFINITE DEPTH.

When wave agitation does not reach the bottom of a body of water it is customary to speak of the depth as infinite, because the wave is not influenced by the existence of a bottom.

PURE OSCILLATION.

Orbits.—In simple oscillatory waves each water particle moves in a circular and closed orbit. The water body itself, therefore, has no onward motion. These orbits diminish rapidly with depth, but so long as agitation does not reach the bottom, the orbits are circles at all depths.[1] The particles on the crest are moving in the direction in which the wave is traveling and particles in the trough are moving with the same velocity in the opposite direction.

Differential movement.—On a line in the direction of the wave movement (hence crossing the waves at right angles) each particle is subject to a gliding between its neighbors. The amount of this gliding is of molecular dimensions, hence not infinitely small. It will be spoken of here as the differential movement of particles. For diagrammatic purposes it is convenient to consider this differential as a considerable arc of the orbit, hence particles are chosen which are removed from one another by a considerable fraction of the length of the diameter.

General form of wave.—In a series of particles moving in equal orbits each particle is more advanced in its orbit (has a more advanced phase) than the one in front of it. If a series

[1] This principle was clearly elucidated by Gerstner in 1804. This and other fundamental principles of oscillatory wave motion are clearly set forth in the report of the brothers Weber on their experiments conducted in the early part of the last century. See "*Wellenlehre*, ERNST HEINRICH und WILHELM WEBER, Leipzic, 1825. This report also summarizes Gerstner's work and all other previous studies on waves from the time of Newton to 1820.

of orbits be drawn and the positions of the several particles be connected by a curved line, that line will show the wave form (Figs. 1 to 6). The curve is a trochoid.[1] It may be produced by rolling a circle on the under side of a straight horizontal line.

Fig. 1

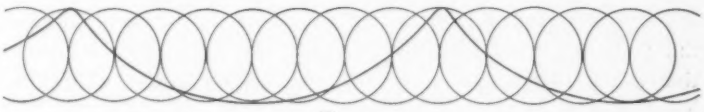

Fig. 2

Fig. 3

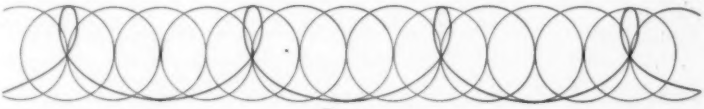

Fig. 4

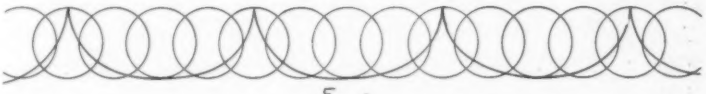

Fig. 5

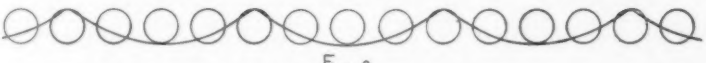

Fig. 6

[1] First recognized by GERSTNER, *Theorie der Wellen*, Prague, 1804. See p. 343 of reprint in WEBER'S *Wellenlehre*. Discussed mathematically by W. J. M. RANKINE, "On the Exact Form and Motion of Waves at and near the Surface of Deep Water," *Philosophical Transactions*, 1863, page 127.

The path generated by any point within the circle is a trochoid. This line will be sharply curved or broadly curved, approaching straightness, according as the point which generates it is chosen near the circumference or near the center. The distance from the center to the generating point is called the tracing arm. When the point is at the circumference—that is, when the tracing arm equals the radius of the rolling circle—the curve is cusped at the top and is the common cycloid (see Fig. 8). This is the steepest and shortest form which a true wave can have. If the tracing arm be longer that the radius of the moving circle the curve is looped instead of cusped (*Fig. 4*). The failure of the water surface to assume these looped forms results in breakes.

Steepness dependent on differential movement.—If the same series of particles in their orbits be represented in several diagrams, assuming for each diagram a different amount of differential movement, the wave will be found to be long when the differential movement is small, and short when the differential movement is large (compare Figs. 1 and 2). If the size of the orbits be increased while the distance between the particles remains the same, and at the same time the differential movement continues to be a certain arc of the orbit, the wave-length remains the same, but its height and steepness increase (compare Figs. 1 and 3). If the size of thc orbit be increased and the differential movement remain the same in absolute amount, instead of the same in arc, the shape of the wave will be preserved and its dimensions increased with the dimensions of the orbit (compare Figs. 2 and 3). If the differential movement exceeds a certain limit the curve will loop (see Fig. 4). This condition corresponds to that of breaking waves as noted above.

Movement of particles below the surface.—If a series of equidistant particles be considered which lie in a vertical line in still water, the movement of the topmost or surface particle is represented by any one of the orbits considered above. That of the second one is similar in every way except in size of orbit and hence in velocity. Its orbit is smaller and described in the same

time. The two particles have always the *same phase* and hence their movements are parallel at a given instant. The same is true of the third particle and all below it, the orbits decreasing in a descending geometrical progression (Fig. 7).[1]

This fact is to be taken with one above stated, namely, that if orbits be decreased while the angular differential movement remains constant, the sharpness of the trochoid curve is reduced. It results from these properties that in a breaker where the curve of the surface would intersect itself, and is therefore impossible, the trochoids below the surface would show less of looping until a level is reached where normal wave motion is going on (compare Figs. 4, 5 and 6).

Lines of like phase.— If the orbits of a vertical series of particles be represented in diagram (see Fig. 7) and the corresponding points on the circles be connected with lines, then the line connecting the highest points and that connecting the lowest points of the several orbits are seen to be straight and vertical. The remaining lines are curved and inclined. In Fig. 8 these lines of like phase are shown in the positions where they occur in the wave. The particles ranged along any one of these lines would be in a vertical line if the water were at rest, just as all particles on one of the trochoid curves would lie in a horizontal line.[2]

Consequences of the trochoidal form and of decreasing orbits below.— If a horizontal plane be passed midway between the level of the crests and that of the troughs it will pass through the centers of the orbits described by the surface particles. All the water at the surface above this plane will then have a forward component, and all the water at the surface below this plane will have a backward component. An inspection of the diagrams will show that the crests are steeper and shorter than

[1] RANKINE, *loc. cit.* p. 131. RUSSELL, "Report on Waves made to the meeting of the British Association 1842–3," reprinted in *The Wave of Translation*, London, 1885, gives formulæ adapted from Gerstner for the rate of orbitical diminution with depth.

[2] RANKINE, *loc. cit.*, p. 129.

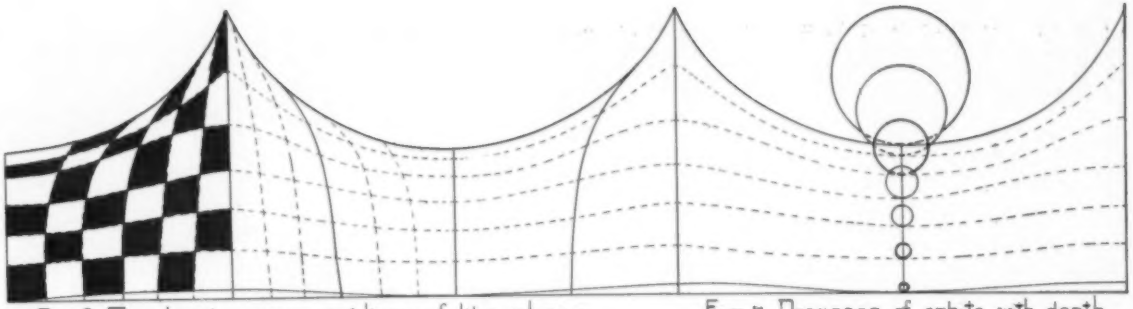

Fig 8 Trochoid curves and lines of like phase.

Fig. 7. Decrease of orbits with depth

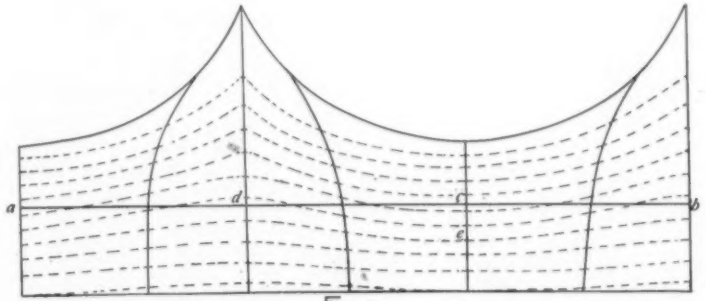

Fig 9.

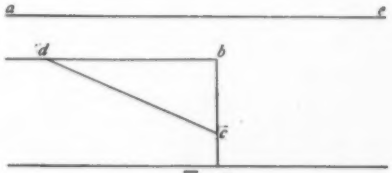

Fig. 10.

the troughs. This contrast increases as the wave shortens (compare Figs. 1, 2, and 5). The crests have not a sufficient volume of water to fill the troughs, and hence the level of the water at rest is lower than the level of the centers of the orbits which the surface particles describe. The lifting of the mean position of particles above their normal level gives a store of potential energy in the wave in addition to the kinetic energy of the motion of the water. It may be shown that this energy of position is exactly equal in amount to the energy of the water's motion.[1] This lifting and this store of potential energy are at a maximum when the wave has its greatest steepness (when it has the cycloid form).

The surface layer is thus divided into strips, in one-half of which the water is moving forward, while in the other half it is moving backward at the same rate. The peculiarity of the case lies in the fact that the backward moving strips are broader than those moving forward. Fig. 8 shows that the same is true in less degree of layers below the surface. Nevertheless, the amounts of water moving in the two directions are equal because of the greater thickness of the layers in the forward moving strips. The contrast of thickness and also of breadth disappears with depth.

MOVEMENTS DURING WIND.

Effect on size and form.—The immediate effect of wind in the direction of wave movement is to accelerate the movement of the particles on the crest. It also retards the backward motion of those in the trough, but this effect is smaller because these particles are largely protected from the wind. The result is (1) an increase in the size of the orbits; (2) an increase in the differential movement of the particles at the surface; (3) more rapid traveling of crest than trough, hence greater steepness in front. The first would result in increasing both height and length of wave in the same proportion. The second results in greater steepness, that is, a shortening in proportion to their height. The increased differential movement is accompanied by

[1] *Ibid.*, p. 132.

increased friction which comes at length to consume all the energy derived from the wind which cannot then further increase the height of the waves. The opposite effects are seen when the wind has ceased. Friction gradually diminishes the differential movement of particles and the size of the orbits. Waves then become lower and at the same time longer in proportion to their height.

Periodical large waves.—The change of wave-length must be propagated downward gradually. If such propagation were immediate, the wave-length at the surface would always be equal to that below. Not being immediate, there may be at times considerable differences in length. The periodical large waves always seen in a storm, may result from composition of lower and upper waves having different periods, as well as by composition of surface waves of different systems.

WAVES IN WATER OF FINITE DEPTH.

Wave base.—The extent of orbital movement decreases in geometrical progression with depth. A point is therefore reached where the force is too small to overcome the viscosity of the water. Before this point is reached and at comparatively small depths the movement is so slight that it cannot affect the smallest solid particles resting on the bottom. This level, below which the largest waves are inoperative, has been called wave-base. Its depth for any given lake or part of the ocean is a function of the height and length of the largest waves.

Behavior of water above wave-base in pure oscillation.— Before considering the action of water on a bottom which lies above wave-base it will be convenient to examine its behavior at any horizontal plane passed through a system of waves. Referring to Fig. 9, let *AB* be such an ideal plane. Being above wave-base it is in the region where the "planes of continuity" (planes including always the same particles which are in a horizontal plane when at rest) are in trochoid curves. The lines of like phase are inclined toward the crests; hence the layer of water included between two planes of continuity is not only thinner

but broader under the troughs than under the crests. *In any one such layer* the water is moving forward under the crests (point *D*, Fig. 9) at the same velocity with which it moves backward under the troughs (point *E* of same layer). Of two adjacent layers the lower one is composed of slower-moving water. The line *AB*, drawn in a horizontal plane, traverses higher layers of water under troughs (at point *C*) and lower layers under crests (point *D*). Therefore the backward moving water along this plane has a more rapid motion than that moving forward. The area covered by it on the horizontal plane is also more than that covered by the forward moving water. This excess of backward movement below is the necessary correlative of the excess of forward movement above, for above the plane traversing the centers of the topmost orbits the movement on all planes is forward.

The same when waves are wind-driven.— If now the water be conceived to be driven by a wind, the current movement produced at any given depth must be added to the forward movement in the corresponding strips which lie below the crests, and subtracted from the backward movement in those under the troughs. The forward and backward velocities in any one layer between two trochoidal planes are now no longer equal. When a certain rate of current is reached, the forward movement in the lower layer traversed by the horizontal plane under the crests (point *D*, Fig. 9) will equal the backward movement in the upper layer which the plane traverses under the troughs (point *C*). A certain force of wind will therefore cause a balance of to-and-fro movements at a horizontal plane below the surface. Any greater force will cause an excess of forward motion.

Film representing surface of continuity.— If in one of the surfaces of continuity in a system of waves of pure oscillation, a film could be introduced which is perfectly flexible and frictionless, this film would show alternate depressions and elevations corresponding to those on the surface of the water, but less sharply curved. The curves would progress after the manner of

surface waves. Any one point in the film would rise and fall vertically; any particle of water adjacent to it would continue to describe its normal circle, gliding to-and-fro on the frictionless film and tracing a straight line upon its surface. The diameter of this orbit is represented by the vertical distance through which any point in the film swings. If the water above the film be viewed in cross section, the area in which it is moving forward would equal that in which it moves backward.

Action on a solid horizontal plane surface.—If the film be supposed now to be stretched to a horizontal plane and to become a solid bottom of the ordinary kind, several changes become necessary in the behavior of the adjacent water particles. The up-and-down movement in their orbits becomes impossible, but the to-and-fro movement, tracing straight lines on the surface, can be continued. Observation shows that this does occur, that particles near a shallow bottom move back and forward in straight lines, and that vertical movement gradually appears in the paths of higher particles, these paths being at first very flat ovals, but becoming higher and more nearly circular as the surface is approached.[1]

The energy of the vertical movement thus interfered with is partly expended in friction on the bottom, though it is quite possible that a part of it may be used in an increased horizontal amplitude.[2] It is a matter of observation that this flattening of orbits affects the movements of surface particles as well as of those below.[3] This effect on the topmost orbits is in proportion to the degree of interference at the bottom. Very much elongated orbits indicate large friction, just as circular orbits indicate that there is no appreciable interference at the bottom.

Effect on wave-length, etc.— The immediate effect of retardation of particles in contact with the bottom must be an increased

[1] WEBER, *Wellenlehre*, p. 124.

[2] The observations of the brothers Weber, as recorded in the table given in *Wellenlehre*, p. 124, seem to show that the horizontal motion on a shallow bottom, while less than at the surface, is actually greater than a certain intermediate point.

[3] WEBER, *loc. cit.*

differential movement of adjacent water particles. The laws of fluids require that this differential movement be distributed throughout the series of particles reaching to the surface, though experienced to a less degree as the distance from the bottom increases. It has been shown that increased differential movement implies decreased wave-length. This shortening, accompanied by steepening, may or may not be sufficient to cause breaking. Since these effects are greater at the bottom than at the surface, the lines of like phase will incline forward. These effects — the increased differential movement, the shortening waves, and the forward inclination of lines of like phase — follow from friction on the bottom, but it is immaterial whether this friction be that of the forward-moving or that of the backward-moving water. The forward inclination of lines of like phase indicates nothing as to the movement of the water as a body. The inclination of these lines may be arrived at in another way. The retarded particles below may be thought of as having a decreased angular velocity, and hence a less advanced phase than the upper particles in the same vertical line. This would require that lines of like phase should connect them with upper particles in advance of them in the direction of wave movement.

Comparison of friction in forward and backward movement.— Looked at in cross-section, the area of the backward-moving water above the line *AB* (Fig. 9) is less than the area of forward-moving water. The areas are equal when bounded below by one of the trochoid curves. The area of backward-moving water is made smaller by the substitution of a rigid plane for the depressed part of the trochoid, and that of the forward-moving water is made larger by the substitution of a flat bottom for the curve bulging upward. This constriction and consequent greater friction of the backward-moving water makes itself felt in the form of the wave and in the bodily movement of the water.

Asymmetrical form.— The velocity of propagation of wave crests depends purely upon the behavior of particles in the upper halves of their orbits, while the propagation of troughs

takes account of the lower halves only. It results from a greater orbital velocity in the upper halves that crests are propagated more rapidly than troughs.[1] The necessary accompaniment of this is the asymmetrical form, steeper in front than behind.

Resulting currents.—The constriction of backward-moving water mentioned above may be compensated either by greater velocity or by broadening the area of backward flow. Upon either of these assumptions, or upon the assumption of no compensation, certain conclusions follow from a geometrical inspection of the diagram, and these conclusions agree with observed phenomena.

Assume first that the deficiency in backward movement is uncompensated. This assumption involves an excess of forward movement which would be observed as a current, a well-known phenomenon where waves enter shallow water. On this same supposition of no compensation the area of the bottom covered by the backward-moving water is greater than that covered by the forward-moving water, and the velocity of that moving backward on the bottom is greater than of that moving forward at the same depth, because the former, being under the trough, is nearer to the surface. A current of this type would therefore be distinctly a surface feature which would not wash the bottom in the direction of its flow. It would, in fact, involve a certain amount of counter-current at the bottom, independent of any of the conditions which give rise to undertow.

Assume next that the deficiency of area of backward moving water is compensated in one of the ways above mentioned, either by greater velocity or by broadening the area. In either of these cases the backward movement on the bottom will be in excess, and will suffer more interference by friction than the forward movement will. This greater interference with the backward movement will favor, with each oscillation, a residual advance of the water as a whole, causing a progression in the

[1] Compare also C. S. LYMAN, "A New Form of Wave Apparatus," *Journal of the Franklin Institute*, Vol. LXXXVI, p. 187.

direction of wave movement, by a process which has something in common with walking. In this way also, pure oscillation would give rise to a current.

It is evident then, that when a system of waves of pure oscillation advances over a shallow bottom, any supposition that may be made regarding the adjustment of internal movements will result in a forward flow of water above, and a dominance of movement in the opposite direction below. Owing to friction, the latter alone is never equal to the former. The resulting movement of water in the direction of wave propagation, whether it be viewed as a current or as an increase of the positive over the negative parts of ordinary waves, is not the same as waves of translation, technically so called.[1] These latter obey different laws and move with different velocities. They may be occasioned by breakers, or may perhaps grow out of oscillatory waves by gradual transition, but their movements are characterized by certain features to be mentioned later.

The return current.—As soon as a current is initiated a return of the water becomes necessary. If the process described above be supposed to take place on a shoal without shores this return may take place by another route. In this case the current may proceed as described for an indefinite time. If there is no return over another area by *horizontal circulation*, then the return must be over the same area by *vertical circulation;* that is, either above or below the original current. If the forward orbital movement above exceed the backward orbital movement below, as seems necessary, and no lateral escape is at hand, the pressure due to increased height of the water would cause a counter current which would appear below as undertow.

Action on bottom materials.—The essential value of the consideration of these currents, springing from waves of pure oscillation, is in the necessary conclusion that the *work of such waves is backward at the bottom, and not forward.* The advance of the water described is due to interference with its backward flow. The same friction which impedes the backward movement of the

[1] J. SCOTT RUSSELL, *The Wave of Translation.*

water causes the motion which the water loses to be communicated to the materials of the bottom. The case is roughly analogous to the wheels of a locomotive, which in "flying the track" brush the sand on the track backward.

The case of wind-driven waves.—The above case is applicable only to waves of pure oscillation, which have of necessity been generated in deep water and are advancing over a shallow bottom. If the wind is blowing at the same time in the direction of wave movement, the result will be similar to that found in considering a mathematical plane above wave-base, provided, of course, that the return of the water is by horizontal circulation. The action of the wind increases the forward motion under crests and diminishes the backward motion under troughs. When the effect of this action reaches a certain amount, the influences named above, which give dominance to the backward movement at the bottom, will be counterbalanced, and any greater effect of the wind will give, at the bottom, an excess of forward movement. A moderate effect of the wind is probably usually sufficient to overcome the backward brushing due to oscillation alone. If the return is by vertical circulation, any increase in current above involves an increased reverse current below.

The case of breaking waves.—When waves generated in deep water advance over a bottom sufficiently shallow to cause breaking, a new factor is introduced. In this case there is a tendency to the formation of positive waves of translation, which may sometimes develop typically, though doubtless more often their motion enters in merely as a component. It is in the nature of these that all the particles in and under the wave form move forward and not backward, and the forward motion is the same at all depths.[1] To the extent that this factor enters, the effect on the bottom will of course be to urge material in the direction of wave movement.

[1] See RUSSELL, *The Wave of Translation*, p. 42; *Report on Waves*, p. 307; also D'AURIA, "A New Theory of the Propagation of Waves in Liquids," *Journal of the Franklin Institute*, 1890, p. 460. The last named is a mathematical discussion.

WAVES IN SHALLOWING WATER.

Tendency to enlargement of orbits.—When a system of waves generated in deep water reaches shallow water, certain forces operate to increase the sizes of the orbits, while others produce the opposite tendency. In general the increase of orbital motion is due to the transmittal of the motion of a larger amount of water to a smaller amount.[1]

If the shallow water be separated from the deep water by a vertical face (*BC* in Fig. 10), the change may operate in some manner similar to the following: The deep water on the right side of the figure is agitated to the depth of *C* by waves traveling toward the left. The motion of particles below the level of *B* is influenced by the vertical face *BC*, this influence being greater in proportion to their nearness. Those in contact with the surface must move in straight lines up and down, while those farther away describe ovals whose longer diameters are vertical, and whose shapes become more circular with distance from *BC*. The energy of the horizontal motion thus lost is, of necessity, partly expended in friction on the vertical face. That which remains must be devoted to increasing the vertical movement. By this means it is again communicated to the particles above the level of *B*.

If the change from deep to shallow water be gradual, the analysis of the process is essentially the same. In this case, however, the circular orbits below will give way to straight line movement, not vertical, but parallel to the sloping bottom *DC*. As before, friction will consume a part of the energy which orbital motion has lost, the remainder being expended in increased movement parallel to the sloping bottom. Of this movement the vertical component will go to increasing the vertical axis of the orbits above.

Tendency to diminishing orbits.—Along with the above tendency to increased orbits come two tendencies toward diminution. The first of these is the influence of the flatter orbits of the lower particles. It tends to diminish the vertical movement

[1] Compare C. S. LYMAN, *loc. cit.*, p. 193.

above, but not the horizontal. The second influence toward diminution is the friction on the bottom which is shared by the particles above.

Opposite tendencies simultaneous.— On a sloping surface the opposing tendencies act at the same time. It is evident that in proportion as the slope is steep, sudden enlargement will be favored, and that slow shallowing favors reduction in size because of the long continued action of friction. Theoretically, there should be a grade on which an incoming wave should suffer no change of height, but since the form and internal movements would change, this ideal grade is not of importance in considering the work of water on the bottom.

Tendency to decreased wave-length.— If the supposed tendency toward orbital increase be balanced by the opposite tendency arising from friction, there will, of course, be no increase in the length or height. However, when waves do increase in height, showing that the orbits have enlarged, they are still very commonly diminished in length and of necessity increased in steepness. This is readily explained by the increased differential movement of particles, initiated by friction on the bottom.

Tendency to steepening due to wind.—The largest on-shore waves usually act in conjunction with the wind blowing in the approximate direction of their movement. The effect of wind on waves in deep water was seen to be similar to the effect of a shallow bottom, namely, (1) increase of orbits; (2) increase of steepness; (3) asymmetrical form. These effects may be carried to the point of breaking, even in water of infinite depth (white-caps). On a shallow bottom the effects are increased by the concurrent action of the two factors. Where there is no wind waves are commonly supposed to break in water whose depth is equal to or a little greater than the height of the waves above the level of repose.[1] When waves advancing on a shallow bottom are already strained by the wind, they may break with much regularity in much greater depths of water, equal to perhaps two, three, or four times the height of the wave. Thus while the

[1] RUSSELL, *Report on Waves*, p. 245.

breaker line for waves without wind is far up the slope from wave-base, it may move down indefinitely near to wave-base when the wind is active.

Tendency of wave to recover form.—Suppose a system of oscillatory waves to advance toward a shelving shore until the wave-base intersects the bottom. One effect must be produced here regardless of qualifying conditions. Bottom friction begins and that involves increased differential movement of particles, which is accompanied by shortening and steepening of waves. This implies increased internal friction, which in turn, operates to decrease the orbital motion and therefore wave dimensions. In so doing it would take away the conditions of bottom friction and its results. The wave would then return to its deep water form. Thus there is a chain of consequences from the original interference at the bottom, which involves at first the change of wave form, but later a restoration, the final result being reduction in dimensions only, suited to the diminished depth. Another decrease of depth must then be assumed if the wave be supposed to continue its contact with the bottom. *Thus there is a certain minimum slope for the bottom, upon which the waves may be propagated as a shallow-water wave.* In so far as the wave is affected by increase of orbit due to diminishing amount of water, the effect will be to hasten the deformation and to retard the recovery of form. If the wind is active it would retard the decrease of orbital movement and the minimum slope mentioned would be smaller.

Limit of tendency to recover form.—The greater the reduction of depth, the greater the increment of internal friction tending to reduce the wave size, and the greater this friction, the more rapidly does it operate to accommodate the wave dimensions to diminished depth. This corrective tendency has, however, a limit. This limit is marked by the breaking of the wave. *There is, therefore, a certain maximum slope for the bottom upon which the wave may be propagated without breaking;* at or beyond this maximum the wave breaks and other agencies come in. The effect of wind as before, is to diminish the maximum slope; hence

true breakers (not whitecaps merely) may occur during a wind on a shore where waves of the same size would not break in a calm.

Effect of breaking on wave propagation.—Even when the distortion of wave form has been pressed beyond the breaking point, the effort to recover its form and habit does not cease. This effort is now favored by all the tendencies which existed before breaking and re-enforced by one more arising from the falling crests. As shown in the diagram (Fig. 4), breaking is an expression of conflicting orbits. The water above the node of the hypothetical surface does not continue the curve which it has been describing, but falls confusedly on the front of the wave. Here its downward motion is in direct opposition to the upward motion of the water in front of the crest. Thus, to the molecular resistance of friction, is added mass conflict, both of which operate to reduce wave motion. This reduction is therefore accomplished more rapidly than in the case of unbroken waves. It results from this, that waves often break at some distance from shore, and after traveling a short distance with foaming crests, recover their form and advance a long distance with crests entire. There is a certain slope on which waves will advance with nearly uniform shape and continuously foaming crests. On a gentler slope they will recover their unbroken form; on a steeper slope the first breaking occurs close to shore, and the wave form is speedily lost.

Waves of translation.—When waves of oscillation enter shallow water the habit of the water particles changes and becomes a compromise between orbital oscillation and movement of an entirely different nature, belonging to waves of translation.[1]

The essential features of the positive wave of translation, known also as the *wave of the first order* or the *solitary wave* are, (1) it is initiated by an elevation of the water surface above its normal level; (2) it is propagated without a corresponding trough and without companion crests, being entirely above the undisturbed level of repose; (3) its rate of travel is greater

[1] RUSSELL, *Report on Waves* and *Wave of Translation.*

than that of waves of oscillation, when like wave-lengths are assumed, the two rates having about the ratio of three to two;[1] (4) the water particles move forward and not backward, starting from rest as the wave approaches and coming to rest when the wave has passed; (5) the forward motion of particles at all depths is the same and equal to the volume of the wave divided by the depth of the water; (6) the paths of the particles are semi-ellipses in a vertical plane, the major axis being the distance through which the particle moves forward, and the minor axis varying from zero at the bottom to the height of the wave at the surface. This movement is in no sense the same as that of wind-driven waves or any other oscillatory wave motion compounded with current. It usually coexists with the latter on shallow bottoms, resulting in waves of a hybrid kind; but waves of nearly typical translatory character may sometimes be seen in nature. Whether the waves be of a pure or mixed type, the essential fact here is that a new *factor* has entered, whose action at the bottom is different from that of oscillatory waves and from that of currents.

The fact of this change to translatory character on a gently sloping beach may be seen in the behavior of floating chips which are seen to move forward on crests but not backward between crests. In place of the trough proper is a wide strip whose surface is almost flat and the water of which is standing still. The laws of translatory waves require that they move more rapidly than the oscillatory. This might be expected to reveal itself in broadening intervals between crests as waves take on the translatory character. It is probable that this *may* occur under suitable conditions. The tendency is usually more than counterbalanced by two factors. The first is the decreasing depth which is the main factor in controlling the velocity of waves of translation. The second is the increasing strength of undertow near shore which retards the translatory movement at the bottom.

As to the manner in which this new habit is developed, it may

[1] *Ibid.*, p. 288.

be cited that perfect waves of the first order are produced experimentally by the sudden addition of water at one end of a rectangular vessel, or by the immersion of a solid, or by a sudden pushing forward of the wall of the vessel, the effect in each case being the local raising of the water surface above the level of repose. A corresponding process in lakes or sea where the bottom becomes shallow may be found in the sudden delivery of the mass of water which falls upon the front of a breaking wave. Observation on the shores of large water bodies, such as the great lakes, would indicate that the area over which waves show a translatory element is somewhat definitely limited by the breaker line. It is probable, however, that there is also a more gradual change by which the waves become increasingly positive as the water shallows and the features of waves of the first order are thereby assumed.

If the modifications of oscillatory waves in shallowing water be reviewed while holding in mind the charactertistics of translatory waves as given above, it will be observed that these changes are all in the direction which would favor the conversion of oscillatory into translatory waves. This is seen in the increase of crests with corresponding disappearance of troughs; the growing excess of the forward movement of particles over backward movement and the increased horizontal amplitude of the lower orbits, approaching equality with that of the orbits above. For present purposes it may suffice to adopt the conception of Mr. Russell[1] who thought of the overgrown crest as

[1] The wave of the second order may disappear and a wave of the first order take its place. The conditions under which I have observed this phenomenon are as follows: one of the common sea waves, being of the second order, approaches the shore, consisting as usual of a negative or hollow part and of a positive part elevated above the level; and as formerly noted, this positive portion gradually increases in height and at length the wave breaks, and the positive part of the wave falls forward into the negative part, filling up the hollow. Now we readily enough conceive that if the positive and negative parts of the wave were precisely equal in height, volume, and velocity, they would by uniting, exactly neutralize each other's motion, and the volume of the one, falling into the hollow of the other, give rise to smooth water; but in approaching the shore the positive part increases in height and the result of this is to leave the positive portion of the wave much in excess above the negative. After a wave has first been made to break on the shore it does not cease to travel, but if the

falling forward into the diminished trough in the act of breaking; the trough is more than filled and the excess of water initiates a wave of translation exactly as in Mr. Russell's experiments.

Volume of undertow.— It is not necessary to suppose that the loss of velocity of the undertow is as rapid as the increase of its cross-section. This would be the case if all the upper water moving shoreward should reach the shore before turning back. The volume of the undertow would then also be constant throughout its course and its velocity would be inversely as its cross-section. But even if the loss of motion due to friction and interference of the bottom be ignored, not all the shoreward moving water reaches the shore. The on-shore motion causes elevation of level over a belt of considerable width. This broad elevation constitutes a *head* which is the cause of outward flow below. It may be shown that the average position at which incoming particles turn back and join the undertow, is at the center of mass of the head. This head is greatest at the edge of the water, hence more water turns back at that point than at any other, but the undertow which has its beginning here is constantly being augmented by that which returns toward deeper water without reaching the shore.

slope be gentle, the beach shallow and very extended (as it sometimes is for a mile inward from the breaking point, if the wave be large) the whole inner portion of the beach is covered with positive waves of the first order, from among which all waves of the second order have disappeared. This accounts for the phenomenon of breakers transporting shingle and wreck and other substances shoreward after a certain point; at a great distance from shore or where the shores are steep and abrupt the wave is of the second order, and a body floating near the surface is alternately carried forward and backward by the waves, neither is the water affected to a great depth; whereas, near the shore the whole action of the wave is inwards, and the force extends to the bottom of the water and stirs the shingle shoreward; hence the abruptness also of the shingle and sand near the margin of the shore where the breakers generally run. . . . . The residuary waves given off after breaking are wide asunder from each other, are wholly positive, and the spaces between them, several times greater than the amplitude of the waves, are perfectly flat and in this condition they extend over wide areas and travel to great distances. These residuary positive waves evidently prove the existence, and represent the amount, of the excess of the positive above the negative forces in the wind wave of the second order.—*Report on Waves*, p. 292.

Relation of the phenomena above to agitation on the bottom.—It is to be inferred from what precedes that symmetrical wave form indicates freedom from interference at the bottom, that friction below is great in proportion as crowding, steepening, and asymmetrical form above are prominent, and that where an off-shore breaker line is seen it indicates a maximum of bottom interference. It is understood in all cases that the surface effect will lag a little behind the cause below, and therefore appear a little to shoreward.

PROFILES RESULTING FROM FORCES DISCUSSED ABOVE.

In the actual operation of the forces discussed above, the resulting action on a sloping bottom may be outward at all places, or inward at all places, or outward over one part and inward over another. Forces in either direction may be gradually augmented or diminished. The different forces are capable of different combinations. Each set of conditions will lead to certain features of profile. If there be no change of condition, a permanent profile of equilibrium may be reached. The constant supply of load constitutes an ever shifting condition. Equilibrium as commonly realized depends on the uniformity of this supply.

Factors in profile-making.—The agencies which shape the marginal bottom may be treated in three groups, (1) oscillatory wave action and undertow, carrying material from shore; (2) on-shore currents and translatory wave action, carrying the material toward the shore; (3) currents alongshore. The tendency of the first group is to steepen the slope from the water's edge to the line at which its erosive power ceases, and deposition begins and to reduce the slope beyond that line. There is also for the second group a line of maximum power on the bottom, within which their effect is to steepen the profile by accumulation at the water's edge, and beyond which the slope is reduced by cutting down. Currents alongshore will be introduced later.

Conflict between on-shore and off-shore action.—The first two

pairs of agencies are in conflict as to the direction in which bottom materials are to be moved. If all the water which moves shoreward must return over the same area and as a bottom current, this current would seem to have greater efficiency than the one above, moving in the opposite direction. This is certainly the case where translatory waves are not favored, as where the off-shore slope is steep. Where slope is gentle and translatory waves are well developed, they have one decided advantage. They are short as compared with the distance from wave to wave, hence all the shoreward movement of the water is concentrated into a small portion of the entire time. Divers are said to feel the passing of one of these waves as a sudden jerk between intervals of quiet. The undertow, on the other hand, has a steady flow except as interrupted by these sudden reverses.[1] The laws of energy give to these concentrated movements a much greater efficiency than to the same amount of motion more evenly distributed in time. On many shores of gentle slope, sand is worked landward, and in this process the agency just mentioned is doubtless important. The effect here referred to is that of waves of translation and is therefore inside the breaker line. It might accumulate sand on-shore but not in off-shore barriers. The dominance of shoreward action is essentially temporary (omitting currents alongshore from consideration). Its effect is to steepen by narrowing the slope. This steepening, in turn, is adverse to waves of translation.

Laws of equilibrium; eroding currents.—Ignoring the presence of a bank and the load derived from it, a current of uniform power tends to reduce the bottom to a level surface, that is, to require equal depth throughout. Equilibrium cannot exist on a level bottom where the power of the current is unequal at different places. In such cases, the depth must suffer a corresponding change until the power of water on the bottom is

[1] HENRY MITCHELL, "On the Reclamation of Tide-Lands and its Relation to Navigation," *Report of the U. S. Coast and Geodetic Survey, 1869*, Appendix 5, p. 85. In this paper Mr. Mitchell takes the extreme view that the sea restores to the continent "all the material washed from its bluffs and headlands." Certain exceptions are made for islands.

everywhere the same. A current of uniformly increasing power requires a uniformly increasing depth, that is, a plane slope. The opposite is true for a current of uniformly diminishing power. A current whose power is augmented at an *increasing rate*, as, for example, in geometrical ratio, requires a descent to deep water on a curve which is convex upward. Increase of power at a diminishing rate requires concavity. Loss of power at increasing rates, and loss at diminishing rates, require concavity and convexity respectively.

Uniform cutting or building.—If a uniform current on a level bottom has eroding power, the whole will be cut down at the same time, and the bottom will remain level while depth increases. In this case the load is furnished at all points equally, and is all carried forward at the same rate. If load be furnished in excess of carrying power, and at all points uniformly (as from top or sides), then the level surface of the bottom would be preserved while depth would decrease.

Load derived from the shore.—To make the case applicable to undertow, the excessive load must be supposed to be furnished at the end where the current enters upon the bottom in question. In this case deposition will first reduce the load at the end upon which it enters and at the same time reduce the depth and thus constrict the current, increasing its power. The latter influence will determine a higher level to which the bottom will be built; a level at which the power of the water is sufficient to carry the load which before was excessive. Filling will then advance forward over the bottom, the filled and unfilled portions both being level, the former growing while the latter diminishes, and the two being separated by a slope, mentioned below. It is evident that the depth at which this slope begins is determined jointly by the power of the water, the amount of the load, and the size of the fragments which make up the load.

The front.—The shape of the slope which intervenes between the area which has been filled and the bottom beyond, will be determined by the rate at which the power of the current decreases. If the loss of power were instantaneous, the slope

would be simply the subaqueous earth slope. If it be in any arithmetical progression, the slope will be a plane whose steepness will vary with the rate of decrease, the slope being steeper when the rate is higher. If the loss of power be in some other manner than by arithmetical difference, the slope will show a curve which will be convex or concave according as the rate of decrease is augumented or diminished. In actual deposition by a current advancing into deep water, the decrease of power is at an increasing rate, as may be seen from the following. If a plane slope be assumed, so that depth increases in arithmetical ratio, then the velocity of the current will decrease in similar ratio, but transporting power varies as the square of the velocity, hence its rate of decrease is progressively augmented. This will require convexity of slope, a feature generally observed at the edge of embankments and subaqueous terraces. The general law of equilibrium, as given above for an eroding current still applies; current power is uniform over all parts of the bottom, if by the term *current power* is understood *power with reference to load* and the current considered is the *resultant of all conflicting currents.* In this case, while the current is acually losing power, the loss is balanced by the coincident loss of load, and the uniformity of power in comparison with load is maintained.

Presence of a bank; equilibrium on a slope.—The presence of a bank fixes not only a horizontal limit to the bottom in question, but determines that at this limit the depth shall be zero. This involves a slope. If equilibrium is to exist on this slope in harmony with the general law stated above, the advantage in power due to shallower water on one side must be balanced in one of four ways, (1) the equality of transporting power in deep and shallow water may be partially maintained by the participation of more water where the depth is great than where it is small. In the case of undertow this has been shown to be true; (2) currents in both directions may be stronger, so that the resultant motion in one direction may be more in shallow water than in deep water, it may even be zero or it may be in the opposite direction. The factors of translatory wave motion and on-shore

currents may occasion this condition; (3) the excessive power of the water on the shallow bottom may be employed in the transporting of a greater load or even in erosion. This is quite generally true; (4) the material may be heterogeneous, the larger stones coming to rest in the shallower water because of their ability to withstand the greater agitation at a higher level. Of all these reasons, it will be seen that only the first can provide for a permanent slope: the others depend upon a continual supply of fresh drift.

Necessity of a continuous supply of load.—Suppose now that a short section of coast line be enclosed between perfectly resistant walls or piers perpendicular to the shore line, and extending out to deep water. The transportation of material alongshore will thus be prevented. If the shore also be supposed to be perfectly resistant, so that no new drift can be furnished to the waves, then the profile of equilibrium, toward which the bottom will tend, is a steep descent from the water line to the depth at which undertow becomes ineffective, and then a low slope outward, following the base of effective undertow. This base is necessarily on a slope because of the increasing volume of undertow with distance from shore.

Effect of a supply of drift.—If now, drift be supplied at the shore line at a given rate, filling will occur at the foot of the steep descent leading down from the water line, until the bottom has risen to a level at which the power of the water is sufficient to transport the material at the rate at which it is furnished, and this filling will advance off-shore, ending in a convex front as shown above.

At the shoreward boundary of this filling area is an angle made by the plane of deposition, with the steeper descent leading down from the water's edge to the line at which deposition becomes possible. In an actual case, where the material of the shore yields to erosion, the water's edge is carried landward, and the first descent is not only far from vertical, but in weak material, is very gentle; probably always steeper, however, than the slope made by deposition farther out. This may be observed

on almost any of the coastal charts of the United States Coast and Geodetic Survey. The east coast of Florida furnishes typical illustrations.

Normal profile; cutting coast.—The normal profile then, of a shore where the resultant of transporting power is outward, is a compound curve, which is concave near the shore, passing through a line of little or no curvature, to a convex front. Where this front rests upon the bottom below the reach of currents, the descent merges into the more level bottom by another concave curve, due to deposition from suspension. If the supply of material from the shore be cut off, the entire shelf will be cut down and its slope reduced and it will necessarily be separated from the shore by a steeper slope than before. If, on the other hand, the supply of material be suddenly increased, a smaller shelf will grow from shore on the surface of the older, for the reason that the new load, being greater, is in equilibrium with the currents at a higher level than before. The greater the load, the nearer will the surface of deposition approach that of the water. On the Atlantic coast of the United States, the depth at which the concave curve merges into the plane of deposition varies from three fathoms near the mouths of some rivers, to ten or twelve fathoms where the lead is smaller. On some parts of the Pacific coast, where the lead is small, the concave curve descends to twenty or thirty fathoms.

Normal profile; building coast.—If the resultant of shore action be to carry material landward, the general character of the resulting curve cannot be very different, since this process also produces steepening near shore. In general the velocity of shoreward motion increases with nearness to land. If the effectiveness of this motion increases with its velocity, there is no accumulation until the shore is reached. The shore is then progressively steepened by accumulation, until the force which acts shoreward can no longer carry material up against the growing component of gravity. This landward urging of sediments is commonly thought to be one of the factors in the production of off-shore barriers. It is plain, however, that

unless the power of inward transportation is decreased before reaching the shore, no barrier can form. This decrease may, at times occur, for carrying power will depend not only on the velocity, but on the agitation of waves at the bottom. It has been seen that waves are rapidly reduced in size and vigor in the act of breaking. It is possible, therefore, that when the slope is so gentle that waves recover their form after breaking, thereby showing that oscillatory wave motion has been much reduced, deposition may take place along the line of wave reduction, which is essentially the breaker line. With these conditions alone, however, the growth of this feature would probably be confined to narrow limits by the undertow. It would, moreover, be a very transient feature, a mere incident in the process of shoreward transportation. The steepening of the shore, to which this process is incidental, would rapidly remove the conditions of the incident.

Variations of the compound curve.—The compound curve will be more marked in proportion as the surface of deposition is broad and its slope is gentle. Where it is narrow its significance may not appear from a profile drawn from widely spaced soundings.[1] If all the waste from the land be carried alongshore, the marginal terrace is of the cut type purely, in which the compound curve is not noticeable, the only prominent angle being that where the surface of cutting intersects the original steeper bottom.

Currents alongshore.—If the effect of currents alongshore were the same at all distances from land, they might be ignored as a factor in profile making. Their variation in strength at different distances from shore produces important results. It has been stated above that *for any one current* the power at the bottom with respect to the load must remain constant. It may also be shown that of *two currents*, each of which is furnished with load to its full capacity, the stronger, which may be supposed to dissipate gradually, will be in equilibrium with its load at the smaller depth. Hence if transportation alongshore be

[1] This is illustrated at many places on the Pacific coast of the United States.

distinctly greater in a zone adjacent to the land, a smaller terrace will rest upon the larger. If transportation parallel to the shore line be distinctly greater in a zone off-shore, and the supply of drift be at hand, a ridge will be built along the line of this more effective current.

Barriers.—It has been shown above that when the off-shore slope is too low for equilibrium, and there are no currents alongshore, steepening is effected, in the main, by accumulation at the water's edge, though there may be some small tendency to accumulation at or just within the breaker line. When currents are flowing, they have a zone of greater efficiency along this same line or just outside. This is because the material which they transport is more agitated by wave action, and is to some extent lifted into the current. Excessive transportation along this zone initiates the ridge which may continue to grow until it assumes the functions of the beach. It this then called a barrier.

The essential function of the barrier is to steepen the bottom slope by carrying the shore line farther out. If the slope is not abnormally low, the barrier is not needed; nor are the conditions present which make its formation possible, one of these conditions being that the agitation on the bottom at the breaker line should exceed that nearer shore. It was seen above that this condition is present, only on a deficient slope.

The slope may become deficient in several ways. The currents themselves might be the cause; or it may result from the sediments delivered by streams, as at many places on our Atlantic coast; or the gentle slope may have belonged to the original bottom over which the waters rose, as seems to have been the case with Lake Michigan in its former extension in the vicinity of Chicago. Doubtless far the most frequent occasion of deficient slope is the falling of the water level or the rising of the shore. That the immediate off-shore slope should in this case be too low, is the necessary consequence of the concavity of the normal slope near shore. The slope from the Atlantic shore line, where well removed from rivers, as on the

east coast of Florida, is perhaps ten fathoms in the first two miles, but if the sea level should fall ten fathoms, or the land should rise by that amount, the new ten-fathom line would lie many miles off-shore, and new barriers might be expected. On some of the small lakes of Wisconsin, especially those without outlet, as Silver Lake of the Oconomowoc group, the falling level has found a deficient slope and barriers are constructed.

The front of the marginal shelf.—If the marginal shelf be a pure wave-cut terrace with no addition by deposit, its limit will be marked by an angle where the plane of the shelf meets the original bottom. The depth of the shelf at this edge will constantly approach wave-base, for it may be safely assumed that wherever waves can agitate, there will be sufficient current to transport. If there are currents strong enough to erode below wave-base, the shelf may be cut still lower. The hardness of the rock can make no permanent difference. This is well illustrated even in so young and small a body as Lake Mendota at Madison, Wis., where the sandstone shelves southwest of Governor's Island and Maple Bluff are cut to the same depth as the clay shelves west of Picnic Point and Second Point.[1]

If the shelf is being broadened at the same time by materials carried across and deposited on its front, there will be, between its upper surface and its steep front, a curve convex to the sky as shown above. This steeper slope begins, not at the depth where the power of the water ends, but at the depth at which the power of the water becomes insufficient to carry the entire load. From this depth the slope becomes progressively steeper to the depth at which the movement of the water is ineffective. Off the Atlantic coast of the United States, the depth at which the slope begins to steepen is usually fifty or sixty fathoms, but the maximum of steepness is not attained until a much greater depth is reached. The depth familiarly assigned to wave-base along this coast is one hundred fathoms, and this figure expresses fairly well the horizon at which the maximum steep-

[1] See hydrographic map issued by the Wisconsin Geological and Natural History Survey.

ness is reached. This would mean that currents become unable to carry the *whole load* at fifty or sixty fathoms, and at one hundred fathoms or less, become unable to transport anything except in suspension. If the factor of transportation in suspension did not enter, the front of such a shelf should show the subaqueous earth-slope.

It is commonly assumed as above, that undertow and wave agitation lose their efficiency at the same point, the limit of the former being determined by that of the latter. Probably this is very generally true; moreover, since wave oscillation decreases with depth in geometrical ratio at a high rate, and the decrease of its agitating power is at a rate measured by the square of this same ratio, it may readily be seen that there is a somewhat definite horizon below which wave action is ineffective. Such a condition is signalized by a somewhat definite limit to the sedimentary shelf.

Transportation beyond wave-base.—The undertow may, however, be constricted laterally and preserved from dissipation, as when the water drifts into a re-entrant curve of the shore; or deep currents may result from a system of rebounds. By either of these means the power of the lower water may be increased, so that at depths greater than that of wave-base sand or even gravel may be transported.[1] In such cases no break in the profile may be seen at wave-base. Broad sheets or streaks of sand may cover the bottom to depths far beyond this line. Such troughs as those of the great lakes, in which all the surface water may be drifted simultaneously in one direction, should especially favor vertical circulation with vigorous movements below. Wave-base of Lake Michigan, where revealed by a sharp angle at the edge of a marginal terrace, is sixty or seventy feet below the surface; yet around much of its margin, a sand covered or gravel covered bottom, concave upward, extends outward to several times this depth with little or no evidence of change of slope at wave-base.[2] This is to be expected from the

[1] See H. C. KINAHAN, "The Beaufort's Dyke off the coast of the Mull of Galloway," *Proceedings of the Royal Irish Academy*, Third Series, Vol. VI, No. 1.

[2] Charts of Lake Michigan, War Department.

necessarily powerful undertow. In Lake Mendota, where wave-base is not lower than twenty feet, sands and even heavy gravels are irregularly distributed over the bottom at depths frequently approaching fifty feet. Some lie at the bases of steep slopes which gravity may have helped them to descend, but others are far from slopes and plainly illustrate the erosive power of currents resulting from a concentration of movement along certain lines.

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A NEW COMBINATION WEDGE FOR USE WITH THE PETROGRAPHICAL MICROSCOPE.

THREE different methods are at present in general use for determining the optical character of a mineral with the petrographical microscope. The first of these employs a quarter-mica undulation mica-plate, the second a selenite plate showing the interference color, red of the first order, and the third a quartz wedge whose interference colors run from gray of the first order to red of the third (Newton's color scale).

The underlying principle of these three methods is the same. For the examination of the optical interference figures in convergent light they answer their purpose well, but for the determination of the optical character of minerals in parallel polarized light they all exhibit one common failing. On inserting any one of them into the tube of the microscope the interference color of the mineral in the slide rises or falls abruptly to some other interference color of the color scale. This jump of the interference color, due to the sudden change of the distance between the two rays passing through the crystal, and caused by the insertion of the plate or thin edge of the quartz wedge, which in itself is so thick that it alone shows gray of the first order, is often sufficient to render the determination uncertain. In deeply colored minerals (in certain amphiboles and pyroxenes) this is particularly noticeable, for there the natural color of the mineral hides the interference color to a great extent. On inserting the plate or wedge, one observes a change of color in the mineral, but is often unable to distinguish whether the color has risen or fallen.

This fault is easily remedied by combining a quartz (or selenite) wedge which shows gray first order to red third order, and in which the ray vibrating parallel to the long direction of the wedge has the greater velocity (**a**) with a selenite plate

showing green of the second order, in which, however, the ray vibrating parallel to the long direction has the lesser velocity (**c**). These two plates are cemented one above the other between glass plates (Fig. 1, cross section. Vertical scale exaggerated.)

With this arrangement the central part of the wedge (Fig. 1, A) appears dark between crossed Nicols as the effect of the quartz wedge on the light passing through at that point is exactly compensated by the selenite plate. To the right and left of A, however, the interference colors rise from dark to

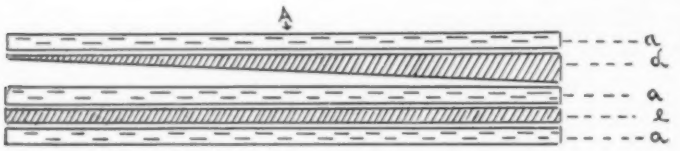

FIG. 1.

blue of the second order at the two ends. This wedge has therefore no noticeable effect on the rays passing through it at the center (Fig. 1, A). The interference color of the mineral seen through the wedge at this point will be the same as though no wedge were there. If, however, the wedge is pulled out or pushed in, the interference color of the mineral either rises or falls, but with a gradual transition from one color to another without an abrupt rise or fall of the color at the start.

Near the center of the wedge is a point for which the difference between the two rays is $\frac{1}{4}\lambda$. This part of the wedge can therefore take the place of the quarter undulation plate.

To make the combination wedge as useful as possible, it was fitted in a metal frame of the same outer dimensions as the ordinary wedge, and with it in the same frame a short selenite plate, red first order, is placed at one end. A space is left free, and is thrown into the field when the wedge is not in use. To steady the motion of the wedge, and also to mark the position of the open space, a small steel spring is screwed onto the tube

above the objective. The small rounded tip at the end of the spring presses up against the metallic rim of the wedge, and at the point where the space is in the center of the field snaps into a small pit made in the rim for the purpose.

The weak point of the ordinary wedges, that the interference colors rise or fall abruptly on their insertion, is thus remedied, and the three plates, quarter-undulation plate, red first order, and wedge are united to one wedge which remains in its place on the microscope, and which it is not necessary to remove after each determination.[1]

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Houghton, November, 1901.

[1] The above wedge was first described in a footnote, p. 275, of "Die foyaitisch-theralitischen Eruptivgesteine der Insel Cabo Frio, Rio de Janeiro, Brasilien," von Fred Eugene Wright," TSCHERMAK'S *Minerolog. petrogr. Mittheilungen.* Bd. XX, pp. 233–306. The combination wedge is made by Voigt & Hochgesang, Göttingen, Germany. Price, 21 M. (*ca.* $5 if quartz be used. [The wedge can also be obtained from Bausch & Lomb.] The price is still less if selenite be substituted for quartz). In ordering, the dimensions of the aperture into which the wedge is to be inserted should be given, also whether the wedge is inserted into the microscope tube parallel to the horizontal cross hair, or at an angle of 45° with same.

THE MORRISON SHALES OF SOUTHERN COLORADO AND NORTHERN NEW MEXICO.

OUTLINE.

I. Introduction.
   1. General statement.
   2. Work previously done, areas examined, etc.
   3. General structure of the region discussed.

II. Places examined.
   1. Rio Cimarron Canyon.
      a. Detailed sections.
      b. Discussion of formations.
      c. Exeter sandstone.
      d. Unconformity at the base of the shales.
   2. Canadian canyon.
      a. Detailed section.
      b. Discussion of formations.
   3. Apishapa Canyon
   4. Foothills region.

III. Summary and conclusions.
   1. The shales of the whole region form a stratigraphical unit.
   2. The shales belong to neither the Dakota nor the Red Beds.
   3. The relation of the shales to other formations.
   4. The possible connection between the Morrison and the Lower Cretaceous.
   5. Correlation of the shales with the Morrison.

THE Morrison formation is known as the Atlantosaurus beds, the Como, and the non-marine Jura. It is a persistent formation composed of colored clay-shales which contain varying amounts of impure sandstones and limestones. Its maximum thickness, so far as known, is about 400 feet, but the average thickness seems to be between 200 and 300 feet. It has an extensive distribution, but the limits are unknown. It occurs in the Black Hills, and has been reported from various parts of Wyoming. It is found over a large part of western Colorado, where it is known as the Gunnison, and outcrops east of the

Rocky Mountains throughout Colorado. Until recently the formation has not been known east of the foothills region of the Rockies, although it was supposed to extend for some distance underneath the younger formations of the plains.

During the past year, 1901, I have been interested in pushing an investigation of this formation as far as possible to the east and south in the hope of finding its limits in these directions; and in the hope also that some light might be thrown upon the age of this formation, which remains a subject of some dispute. In a recent number of the JOURNAL OF GEOLOGY (Vol. IX, No. 4, May–June, 1901) I described certain shales found in the canyons of southern Colorado, and gave reasons for considering them as the probable equivalent of the Morrison formation. Since the publication of that article, these shales have been examined by Mr. Barnum Brown, of the American Museum of Natural History, with a view to opening bone quarries in them. After an examination of several days, Mr. Brown confirmed the opinion that the shales are of Morrison age, and stated furthermore that Dinosaur bones occur from a horizon fifty feet from the base to the top of the formation. He says in a private letter:

> I identified *Morosaurus* and *Diplodocus* vertebræ, and the lithological character of the beds is identical with those (Morrison) extending along the eastern side of the Rocky Mountains.

My present purpose is to report progress in tracing this formation still further to the east and south, where it is exposed in the canyons of southern Colorado and Northern New Mexico.

Over a large part of southeastern Colorado and northeastern New Mexico occurs an extensive uplift, which, roughly speaking, seems to be in the form of an oblong dome, whose axis lies near the Colorado-New Mexico line in the vicinity of Mesa de Maya. From the center, the strata dip more or less in all directions, unless perhaps in a southwesterly direction, where data are wanting. (It is possible that more detailed work will show that the slight southwest dip shown by Mr. Hills in his map of the El Mora and Spanish Peaks regions[1] is only local,

[1] *U. S. Geol. Surv.*, El Moro and Spanish Peaks Folios.

and that the uplift may prove to be an anticline extending eastward from the mountains, rather than a dome.) The dome, if such it be, is in general terms bounded on the north by the Arkansas River; on the west by the Rocky Mountains; on the south by the eastward flowing part of the Canadian River, New Mexico; to the east the dip continues at least to Beaver county, Oklahoma.

The Dakota sandstone occurs throughout this region. It is an easily recognized formation, and conspicuous wherever exposed at the surface. It is, therefore, a convenient reference horizon. Over a large part of this elevated region — perhaps the eastern four-fifths — the Dakota is either the surface formation or lies so near the surface that it is exposed in the numerous canyons. Over the western fifth, the Dakota is buried beneath the younger formations to reappear along the mountain front in a nearly perpendicular reef known as "stonewall." The greatest elevation at which I have identified the Dakota is 6,300 feet,[1] at the point where I crossed the Mesa de Maya. Over a considerable area in the vicinity of Mesa de Maya, the elevation of the Dakota is practically the same. From this region northward there is a gradual descent until the Dakota drops beneath the younger formations near the Arkansas River.[2]

The westward dip of the strata is indicated by Mr. R. C. Hills in the geological maps of the folios just referred to. A study of these maps shows that the Dakota lies about 2,200 feet beneath the surface at Trinidad, Colo., *i. e.*, it lies 3,800 feet above sea level, while twenty-five miles to the east it lies at an elevation of 5,300 feet, and sixty miles east of Trinidad, where I crossed the Mesa de Maya, it lies at an elevation of 6,300 feet. There is then a westward dip of the strata in this region of 2,500 feet in sixty miles, or about forty-one feet per mile on the average. The dip of the strata in the southern, eastern, and

[1] See *U. S. Geol. Surv.*, Mesa de Maya Sheet.

[2] G. K. GILBERT, *U. S. Geol. Surv., Seventeenth Annual Report*, Pt. II, "Underground Waters of the Arkansas Valley in Eastern Colorado," sections following p. 574.

FIG. 1.—Sketch map of Southern Colorado and Northern New Mexico.

northern limbs of the uplift is practically the slope of the surface, and is indicated by the contour lines [1] of the accompanying sketch map. On these three sides, the uplift has been

[1] The contours are taken from the maps published by the U. S. Geol. Surv.

trenched by numerous streams to a sufficient depth to expose the shales which are the subject of this paper.

There is no claim advanced that this vast region has been exhaustively studied. My purpose has been to trace the shales which underlie the Dakota sandstone, over as wide an area as possible. In so doing I have visited the canyons of the Apishapa, the Purgatory, the Rio Cimarron, the Canadian, and their tributary canyons, as well as the foothills of the mountains

Dakota.	Sandstone, massive and quartzitic, somewhat conglomeratic in places.
Shales.	200 feet of varicolored shales with local beds of brittle limestone and lime concretions. A coarse, loose-textured, cross bedded sandstone occurs near the top.
Red Beds.	Deep red sandstone.

FIG. 2 (Sec. I). Taken in the Rio Cimarron, 14 miles east of Folsom, N. M.

where the sedimentary formations are sharply upturned. The itinerary is indicated by the dotted lines on the accompanying sketch map.

Rio Cimarron Canyon.[1]—There are two Cimarron rivers in New Mexico. The one referred to here, which for distinction I shall call the Rio Cimarron, flows eastward near the northern border of the territory, and finds its way through Oklahoma and Kansas to the Arkansas River. A few miles east of Folsom, N. M., the Rio Cimarron cuts through the Dakota sandstone and into the Red Beds beneath. The thickness of the Dakota was estimated at 200 feet at this point. Below this sandstone occurs twenty-five to fifty feet of soft variegated clay-shales, underneath which is a series of gypsum layers inter-stratified

[1] I am greatly indebted to Mr. T. A. Pierce for assistance in this work. He has taken an active interest in furthering the investigation.

with clay. This series in turn rests upon red sandstones of typical Red Beds type. The shales thicken from this point toward the east. In a section fourteen miles east of Folsom, the shales are about 200 feet thick. The gypsum becomes less

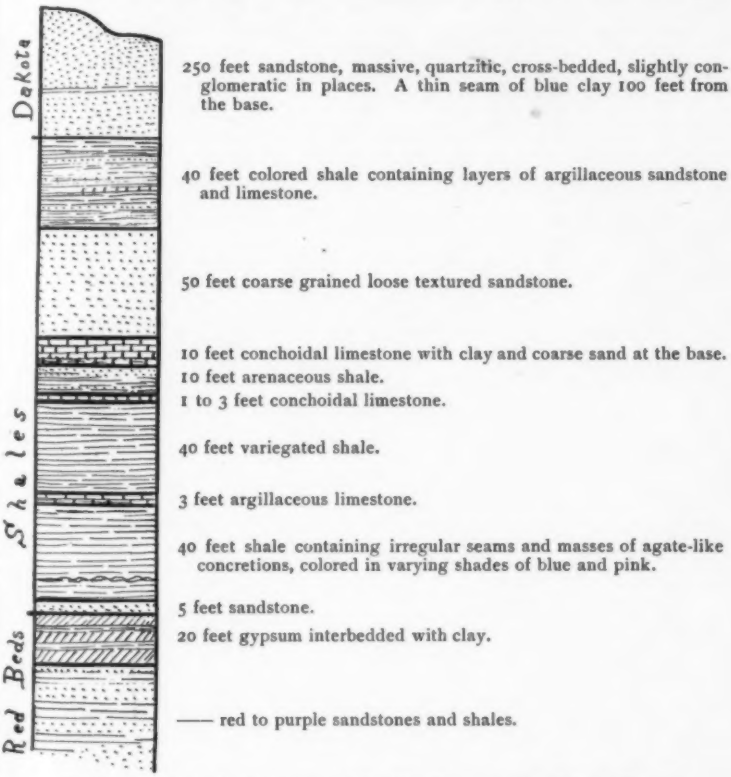

Dakota
Shales
Red Beds
250 feet sandstone, massive, quartzitic, cross-bedded, slightly conglomeratic in places. A thin seam of blue clay 100 feet from the base.
40 feet colored shale containing layers of argillaceous sandstone and limestone.
50 feet coarse grained loose textured sandstone.
10 feet conchoidal limestone with clay and coarse sand at the base.
10 feet arenaceous shale.
1 to 3 feet conchoidal limestone.
40 feet variegated shale.
3 feet argillaceous limestone.
40 feet shale containing irregular seams and masses of agate-like concretions, colored in varying shades of blue and pink.
5 feet sandstone.
20 feet gypsum interbedded with clay.
—— red to purple sandstones and shales.

FIG. 3.—Section 2, in the canyon of the Rio Cimarron east of Long Canyon.

important eastward and is absent in places, as shown in the detailed sections on opposite page.

Still further to the east, below the junction of Long Canyon and the Rio Cimarron, an isolated mesa stands in the midst of the canyon. The sides of the mesa are well exposed and the

out-cropping edges of the formations easily accessible. The upper member of the Red Beds at this point is gypsum. Between this and the Dakota which caps the mesa, occurs about 200 feet of variegated shales containing a subordinate amount of sandstone and impure limestone, as shown in the accompanying detailed section, Sec. 2.

FIG. 4.—Photograph taken near Exeter post-office, N. M., showing the Exeter sandstone at the top of the butte, lying unconformably upon red beds.

The next section taken was a few miles east of Exeter post-office. Numerous buttes and mesas, varying in size from small mounds to table lands many acres in extent, have been left standing in the midst of the canyon in this vicinity. They rise abruptly from the broad, well graded bottom which is several miles wide at this point. The larger mesas are capped by the Dakota sandstone, while the smaller ones have lost their protecting caps. On the butte, shown in the photograph, FIG. 4, the Dakota and the underlying shales, have been removed. They appear however in the point shown at the right in the

photograph, where the third detailed section was taken. The cap rock of the butte is the Exeter formation, to be described beyond. In this region it immediately underlies the shales in place of the gypsum which is absent. No detailed section was taken east of this point, but the outcropping edges of the formations were seen continuously in the canyon sides to a point about seven miles east of the eastern boundary of New Mexico, where the eastward dip of the strata carries the shales beneath the canyon bottom.

In the section east of Exeter, the Dakota rests upon a series of variegated clay shales which contain layers of sandstone and impure limestone, and at this point the limestone attains greater importance than at other places examined in the Rio Cimarron. The brown limestone near the base resists erosion to such an extent that a shelf often several rods wide is produced in the canyon side. In the concretionary limestone near the top was found the only invertebrate fossil obtained from the shale formation of the Rio Cimarron. It is a fragment of a pelecypod too poorly preserved to identify.

The formations represented in the detailed sections, with the exception of the Exeter formation, to be described later, were traced continuously from Folsom eastward to a point seven miles beyond the boundary of New Mexico. The canyon sides are steep and well exposed throughout this distance and no difficulty is encountered in following the outcrops. Throughout this distance the Dakota sandstone forms the protecting rim of the canyon walls, while the middle portions of the walls are as uniformly occupied by the shale formation. This middle formation consists mainly of clay shales of various colors, and friable sandstones, varying from nearly pure silica to various admixtures of clay and sand. In certain places, however, the sandstones are hard, coarse, and slightly cross-bedded. The character of the formation varies laterally within short distances. The limestone which forms a subordinate amount of the formation, may occur at any horizon. The layers are generally less than one foot thick, and never, so far as observed, attain a thickness of

more than a few feet. They vary in character from brittle masses often of a reddish-brown color, to seams of tough admixtures of clay, lime, and sand. All of the members of this formation vary laterally in character and thickness. No two sections exhibit the same order of succession nor the same relative proportion of materials.

There is, however, one feature which is remarkably persistent, and which may deserve special mention. Near the base of the formation occurs a curious nodular seam of silica resembling imperfectly formed agates. These are sometimes loosely held together, with clay filling the internodular spaces, and sometimes gathered into a compact mass. Calcite is also found imbedded in the silica. The silica is obviously a deposit from solution. In many instances it shows a concentric structure with bands of different colors. The color varies from deep red to light blue. The seams bearing this agate-like material are usually only a few inches thick. Either the seams themselves or "float" from them were noted at nearly every point examined in the canyon of the Rio Cimarron, as well as at other localities to be described.

Throughout the extent of the Rio Cimarron, Red Beds occur underneath the shale formation. These Red Beds are composed principally of deep red to purple sandstones, although more or less red shale is interstratified with them. In the upper twenty-five miles of the canyon the upper member of the Red Beds series is gypsum. In the lower or eastward part the Exeter formation, to be described later, takes the place of the gypsum between the Red Beds and the shale formation, and lies unconformably upon the Red Beds.

I have previously shown[1] that the Dakota sandstone extends from the Purgatory and its tributary canyons to the Rio Cimarron and that a shale formation similar to the Dinosaur-bearing beds of the Purgatory was found beneath the Dakota. It is obvious, therefore, that the protecting sandstone of the Rio Cimarron is Dakota. No vertebrate fossils have been found in

[1] JOUR. GEOL., Vol. IX, May-June, 1901.

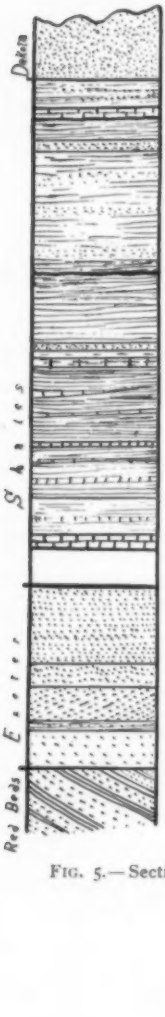
the shales of the Rio Cimarron, although ranchmen from that vicinity report having seen large petrified bones. A comparison of this formation, however, with the shale formation of the Purgatory, indicates that the two are identical in composition and stratigraphic position, and leaves little room for doubt that they are parts of one and the same formation.

In the vicinity of Exeter post-office the shales are separated from the underlying Red Beds by a well-marked unconformity. The Red Beds were thrown into gentle undulations and these undulations eroded previous to the deposition of the younger sediments upon them. Several miles west of Exeter post-office the shales rest upon the eroded edges of a local arch, from the top of which about sixty feet of the Red Beds had been removed previous to the deposition of the shales. The gypsum, which is here considered as the top of the Red Beds, appears in the flanks of the truncated arch. From this point eastward for several miles angular unconformities were noted at the top of the Red Beds. In the vicinity of Exeter, the thickness removed by erosion is considerable, but no attempt was made to estimate it. The dip of the truncated Red Beds may be estimated from the accompanying photograph (Fig. 4).

Near Exeter post-office a sandstone formation appears between the Red Beds and the shales. It lies unconformably upon the Red Beds as shown in the illustration (Fig. 4). The cap rock of the butte at the left is this new formation, which I shall for the present call the *Exeter sandstone*. It is a firm, hard and rather coarse but evenly laminated sandstone, pink to white in color. The lower strata are pink, while those above grow progressively lighter colored. It has the appearance of being composed of the coarser material from the eroded Red Beds, and may be a basal sandstone formed by the encroaching waters from the east or south, which cut away the Red Beds. The sandstone has a maximum thickness of seventy-five feet, and extends from a point several miles west of Exeter, where it thins out, eastward to the New Mexico line where it drops beneath the canyon bottom. No fossils of any kind were found in this sand-

stone. Wherever it occurs it forms a series of nearly perpendicular cliffs, thus making a broad conspicuous band along the canyon sides.

It is evident, then, that the shale formation rests in turn (1) upon the gypsum conformably; (2) upon the gypsum and the underlying Red Beds unconformably; (3) upon the Exeter sand-



78 feet of hard quartzitic sandstone.

10 to 15 feet of shale, arenaceous in places.
6 inches lime concretions.
8 feet red shale.
4 feet sandstone.

50 feet sandstone and shale (débris covered in places).

30 feet dark red shale.

4 feet coarse sandstone.
2 feet blue clay.
2 feet calcareous clay.

30 feet blue clay shale with seams of limestone.

1 foot hard brittle limestone.

20 feet shale with thin seams of impure limestone.

10 to 15 feet shale with impure limestone and sandstone bands and irregular masses of agate.
5 feet hard brown, nearly pure limestone.

20 feet (unexposed).

35 feet white sandstone, massive below but passing to well defined layers above.

8 feet loose textured and readily weathering sandstone.
15 feet massive chalky white sandstone, cross-bedded and cavernous weathering.
2 feet soft shaly sandstone.
15 feet massive evenly laminated sandstone, ranging in color from red at the base to white at the top.

—— red sandstone layers interstratified with red and purple shales.

FIG. 5.—Section 3, near Exeter post-office in the canyon of the Rio Cimarron.

stone conformably. It is noted, furthermore, that the shales, as a formation, do not vary in any marked degree either in character or thickness. Whatever may have been the physical conditions prior to the deposition of the shales, it is evident that the shales were deposited over a well-graded surface. It follows also that there was a somewhat notable time-interval between the Red Beds and the shales. A part at least of this time-interval is represented by the unconformity between the Red Beds and the Exeter sandstone. It is uncertain whether there is a time break between the Exeter sandstone and the overlying shales. However this may be, the seeming conformity which exists in many places between the Red Beds and the shales is deceptive. The contact really represents the whole time indicated by the unconformity between the Red Beds and the Exeter sandstone and the time required to form the Exeter sandstone, besides the possible period between the deposition of the Exeter and that of the shales.

The region south of the Rio Cimarron.—In the course of the journey from the Rio Cimarron to Clayton and thence westward to Springer, no stream was found which had cut entirely through the Dakota sandstone until the Canadian River was reached. There is, therefore, a space of about sixty miles—the space by which the nearest points of the Rio Cimarron and Canadian canyons are separated—in which the shale formation was not seen. It has been penetrated, however, by wells. One well several miles northeast of the Don Carlos hills—nearly due south of Folsom—was drilling at the time I visited the region. The drill had penetrated the Dakota sandstone and was then cutting through a series of soft shales. The engineer in charge of the work described the formation as "a soft clay of different colors containing a few sand layers and thin seams of a *smooth whetrock without any grit.*" The "whetrock without any grit" was probably one of the argillaceous limestones of the shale formation.

Canadian Canyon.—The canyon of the Canadian begins where the river penetrates the Dakota sandstone a few miles south of Springer, N. M. For about fifty miles it is a narrow gorge sev-

eral hundred feet deep, but further to the south and east it widens to a broad gently inclined plain, bordered by escarpments 500 to 1,000 feet or more in height. The preservation of the escarpments is due principally to their capping of Dakota sandstone, but in some places extrusive sheets of lava form the surface rock. The canyon walls were examined at intervals as far south as Bell Ranch. From Canyon Largo, eastward, I followed along the base of the northern escarpment continuously for about thirty miles. Sections were studied, in more or less detail, at Mill's Ranch and at the toll road crossing, and at several points east of Canyon Largo. A detailed section taken at the edge of the escarpment north of Bell Ranch (Sec. 4) may be taken to represent the structure of this region. The thickness of the capping sandstone was not taken. It is the surface rock, and its thickness varies, due to surface erosion. Its original thickness does not seem to differ materially from that of the Dakota as described for the plains region in general. It was estimated at something over 300 feet. Its character differs in no obvious way from that of the Dakota described in other places. It was traced with little interruption from the Rio Cimarron to the Canadian and throughout the region examined. It is massive, quartzitic, slightly conglomeratic, and being so much more resistant than the shales and softer sandstones beneath, always forms escarpments in the regions where it has been trenched by the streams.

The lower parts of the canyon walls are made up of Red Beds. No attempt was made to study these further than to determine their relation to the overlying shales. A thickness of several hundred feet of the Red Beds is exposed where the canyon is deepest. They are deep red to purple, easily disintegrated sandstones and shales except the upper 50 to 100 feet or more in thickness. This upper series is composed of sandstones which differ so materially from the strata beneath that they may be considered as possibly representing a separate formation. They are massive, red to light pink sandstones, and form a conspicuous cliff throughout the length of the region examined.

Between the Red Beds and the Dakota occurs a shale and

250 feet sandstone, coarse, massive and quartzitic.

50 feet variegated shale containing numerous thin bands of limestone and sandstone.

10 feet argillaceous fissile sandstone.

13 feet coarse sandstone.

45 feet bluish-green shale with a few bands of sandstone and impure limestone.

15 feet coarse massive sandstone.

12 feet variegated clay shale.

5 feet white sandy shale.

13 feet coarse white sandstone, cross-bedded in places.

15 feet colored sandy shale.

6 feet argillaceous sandstone.

15 feet coarse sandstone containing lime concretions in places.

36 feet variegated shale containing thin layers of sandstone.

12 feet red and green shales.

65 feet poorly exposed. Shale seen at intervals.

10 to 50 feet rusty brown to red sandstone with bands of red clay.

50 to 100 feet massive pink to white sandstone. Forms a persistent cliff.

—— Friable sandstones and shales in thin layers, red to deep purple in color.

FIG. 6.—Section 4, taken at the escarpment north of Bell Ranch.

sandstone formation approximately 300 feet thick and composed principally of variegated clay-shales and friable sandstones. Limestones of varying degrees of impurity occur with more or less frequency according to location. At the point represented in the detailed section (Sec. 4) the limestone layers are nearly all at the top. A few miles from this point a well exposed section exhibited no limestone near the top, but a stratum of bluish-green limestone several feet thick occurs near the middle. In no two sections studied do the limestones occur at the same horizon. The sandstones of this formation in the Canadian Canyon compose a notable part of the thickness (about one third to one half). The various layers differ in character from firm, well-cemented masses to beds of loose-textured sandstones which disintegrate with the greatest ease. They vary from masses of nearly pure silica through various admixtures of sand and clay to nearly pure clay. Near the middle of the formation occurs a slightly cross-bedded layer of sandstone which seems to be more persistent than the others, although this cannot be confidently stated. The shales are soft and weather readily except where they are intermingled with sand or lime in sufficient quantities to render them resistant. They are colored in various shades of red, brown, and green. In short, they differ in no obvious manner from the shales which I have already described from the canyons of the Rio Cimarron and the Purgatory.

The transition from the massive sandstone (Dakota) at the top to the shale formation is abrupt, but no definite evidence of unconformity was seen. The base of the shales is not marked here by gypsum as in the canyons of the Rio Cimarron and the Purgatory. In its place occurs the coarse, massive pink sandstone shown in the section and in the photograph (Fig. 7). No evidence of unconformity was found at the base of the shales, and the line of delimitation is drawn at the top of the heavy sandstone because of the marked change in character and composition at this horizon. No fossils were obtained from the shale formation of the Canadian, and its correlation must rest, for the present, entirely upon stratigraphic and lithologic

grounds. There is little doubt that the upper sandstone belongs to the Dakota. It is possible, however, that there may be some question regarding the lower limit of the Dakota. In the canyon of the Purgatory, the Dakota sandstone rests upon variegated shales which are in places full of Dinosaur bones. There can be

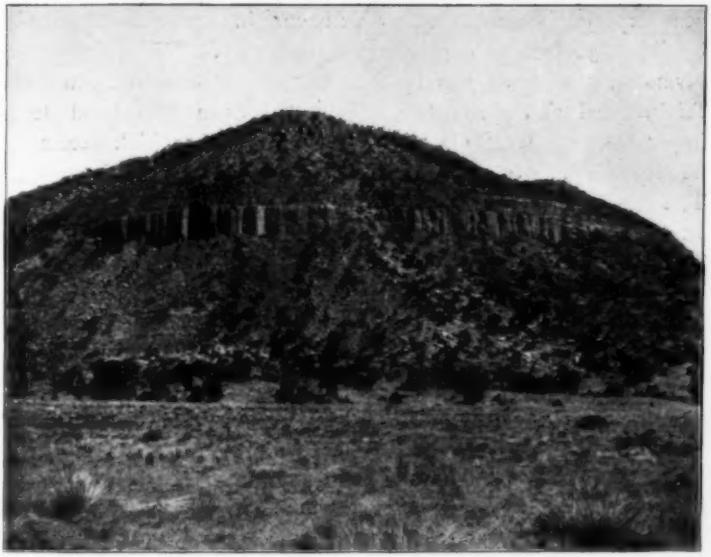


FIG. 7.—The Canadian escarpment west of La Centa Canyon, N. M. The summit is Dakota. The gentle shape near the top is occupied by the shales, with heavy sandstone at the base. The massive "columnar" layer—100 feet thick—is the upper part of the Red Beds—the possible Trias. The lower portion is occupied by the Red Beds (Permian).

no doubt in this case as to where the line of separation should be drawn. The same change of character in passing from the Dakota to the shales obtains in the canyons of the Rio Cimarron and the Canadian. It is therefore probable that the lower limit of the Dakota is properly placed at the lower limit of the massive sandstone, and that the shale formation beneath is separate and distinct from the Dakota, although conformable with it. It is

furthermore probable that this shale formation of the Canadian is identical with that of the Rio Cimarron and the Purgatory.

Apishapa Canyon.— East of Walsenburg, Colorado, the Apishapa River cuts through the Dakota sandstone, making a sharp, narrow canyon several miles long and something more than 300 feet deep at the deepest place.[1] The greater part of the thickness exposed is sandstone. This occurs in two series separated by about 30 feet of dark colored clay-shale. The upper series forms the protecting rim of the canyon. It is about 100 feet thick, hard and quartzitic, and contains an occasional leaf impression. It weathers to a rusty brown color which seems to be characteristic of the upper part of the Dakota in this region. The lower series is massive, white, and less strongly quartzitic. In places the uneven induration permits cavernous weathering. The dark clay-shale between the two series is probably the layer of fire clay which usually occurs about the middle of the Dakota. Near Thatcher, Colorado, a few miles east of the Apishapa Canyon, fire clay is mined to some extent at a horizon which is evidently the same as that occupied by the dark shales of the Apishapa. The fire clay of Thatcher and the dark shales of the Apishapa are similar in color, character, and position, and are probably parts of one and the same deposit. Below the lower sandstone about 50 feet of somewhat highly colored shale occurs. In composition and character this shale is similar to the shales found in the Red Rocks Canyon, several miles to the east, underlying the Dakota sandstone, and are probably identical with them.[2] On the other hand a similar shale formation, and similarly placed, occurs in the canyon of the Huerfano River a few miles west of the Apishapa. The shales of the Huerfano are described by Mr. R. C. Hills in the Walsenburg Folio of the U. S. Geological Survey, and referred to the Morrison. There is little doubt, therefore, that the shales exposed in the bottom of the Apishapa Canyon belong to the Morrison.

Extension along the mountains.—Along the mountain front

[1] See *U. S. Geol. Surv.*, Apishapa Sheet.

[2] See Sec. 2, p. 347, JOUR. GEOL., Vol. IX, No. 4, May–June, 1901.

west of Trinidad, Colorado, the sedimentary formations are strongly upturned. In some places they are even overturned to such an extent that the apparent dip to the west is something like 30 degrees. A sharp "hog-back" in this region is locally known as the "stonewall." The name is derived from a quartzitic sandstone which, on account of its resistance to erosion, forms a ridge parallel to the mountain front. The serrate edge of this sandstone, which rises in places several hundred feet as a sheer wall, forms the crest of this ridge. This sandstone contains fossil tree trunks and branches. Stratigraphically above the sandstone lies a series of shales and limestones which yield fossils of Colorado-Cretaceous type. Beneath the sandstone lies a series of shales, sandstones, and limestones, which in turn is underlain by an extensive series of red sandstones—the Red Beds of the mountain front. Stratigraphically and lithologically the "stonewall" is identical with the Dakota sandstone as described from various places along the mountain front. This stonewall was traced from La Veta, Colo., southward to Gold Creek, N. M., a distance of about 40 miles.

The shale series lying between the Dakota and the Red Beds is composed principally of variegated clay-shales, with varying amounts of friable sandstones and a few thin seams of impure limestone. The best exposed section found is near the town of Stonewall, Colo., but no satisfactory place was found for making a detailed section, owing to the growth of underbrush and to the surface débris. The total thickness, where upper and lower contacts could be located, was estimated at 300 feet. The shales, sandstones, and limestones of this formation are stratigraphically and lithologically identical with those described from the canyons to the east and south. They are also identical with those described by Mr. Hills from the Walsenburg area a few miles to the north. They were identified on the north fork of the Purgatory, at the town of Stonewall, and at Gold Creek, N. M. There are strong indications that the shale underlies the Dakota continuously throughout the length of the region examined along the mountains.

Summary and conclusions.—It seems evident from the foregoing data that the shales lying beneath the Dakota sandstone in this region are found, with little variation in thickness or character, from the foot of the Rocky Mountains eastward to Oklahoma and southward to the Canadian River wherever streams have cut deep enough to expose them. This persistency in thickness and general character exhibited by the shales wherever exposed, forces the conclusion that the formation was originally continuous, at least over the area represented by the accompanying map, and leads naturally to the inference that it extends far beyond these limits. The absence of paleontological data from the New Mexico areas leads to doubt concerning the integrity of the formation over the whole area. In the absence of such data, we must resort to stratigraphic and lithologic proofs. Since the shales lie between the Dakota above and the Red Beds beneath with apparent conformity except in the canyon of the Rio Cimarron, it may not be evident to those unfamiliar with the field relations that they compose a formation distinct from the Dakota on the one hand and the Red Beds on the other. In the Purgatory Canyon the contact is sharp between the Dakota sandstone and the Dinosaur bearing shales. In the Rio Cimarron and Canadian canyons there are equally sharp contacts between the upper sandstone and the underlying shales, and these are lithologically identical with the Dakota and the shales of the Purgatory. There is, therefore, little probability that the shales belong to the Dakota.

There is even better evidence that they do not belong to the underlying formations. In the Purgatory and Rio Cimarron canyons they are separated from the Red Beds formation by a gypsum series which is here considered as representing the closing stage of the Red Beds period. As already stated, there is in the Rio Cimarron an angular unconformity between the shales and the Red Beds where the shales are seen resting upon the truncated edges of the upturned gypsum and underlying red strata. Where the Exeter formation occurs, the shales overlie it conformably, but the marked contrast between the two series

leaves little room for doubt that they are two distinct formations. A similar contrast is apparent in the canyon of the Canadian and the exposures along the mountain front. There is little doubt, therefore, that the shales are separate and distinct from the Red Beds.

Wherever the shale formation was found in this region its character is the same. Minor variations occur constantly within the formation, which in themselves constitute one of its most persistent features. The clay-shales vary laterally, as well as vertically, through arenaceous shales to sandstone on the one hand and through calcareous shales to pure limestone on the other. The members of the formation, however, are in general easily distinguished from the Dakota above and from the Red Beds beneath. There are wide areas within the region in which the shales are not exposed. But their lithological character wherever seen leads to the inference that throughout the region examined the shale series is one and the same formation.

The age of the formations underlying the shales is not definitely known. The Red Beds along the base of the mountains have been called Triassic by many geologists, while some portions at least have been referred to the Carboniferous by others. The Red Beds of the Purgatory Canyon seem to differ in no essential manner from those near the mountains, unless it be in the greater massiveness of the upper series—the upper 100 to 200 feet of the Purgatory Red Beds being massive sandstone. The Red Beds of the upper Rio Cimarron seem to be indentical with those of the Purgatory and the mountain front. Those of the lower Rio Cimarron are less massive, and composed of thin seams of red sandstone interstratified with red to purple shales. In this respect they resemble the lower series of the Red Beds exposed in the Purgatory.[1] The unconformity at the summit of this series indicates that the upper portion of the Red Beds has been removed. The Exeter sandstone entering from the east or south and thinning towards the west lies unconformably upon the Red Beds. The Red Beds of the Canadian, with the excep-

[1] LEE, JOUR. GEOL., Vol. IX, No. 4, May–June, 1901, Sec. 1, p. 346.

tion of the upper 50 to 100 feet, seem to be identical with the lower series of the Rio Cimarron and the Purgatory. The Red Beds of the Canadian are referred to the Permian by Mr. R. T. Hill,[1] While the age of the Red Beds is not of first importance in my present purpose, it may be noted incidentally that no distinction was found between the Permian of Mr. Hill at the south, and the so-called Trias at the north and west.

The Exeter sandstone is separated from the Permian by a time break in the Rio Cimarron. Its character and general field relations are similar to the upper massive series of the Canadian Red Beds. While there was no evidence of unconformity noted in the Canadian, it is possible that the upper series is of the same age as the Exeter sandstone. Mr. Hill, in his description of the Texas Region, speaks of a thin formation overlying the Permian which is referred to the Trias with some doubt. He says: "The existence of the early Mesozoic (Triassic) is doubtful although possible. Rocks referred to this period overlie the Permian along the western part of the Central Province, and appear in small areas around the border of the plateau of the plains."[2] The latter region embraces the southern portion of the area under consideration in this paper. It is possible, then, that the upper part of the Red Beds of the Canadian and perhaps the Exeter sandstone of the Rio Cimarron may be of Triassic age. If this be true the shale formation rests upon both Permian and Triassic rocks.

On the other hand, the Exeter sandstone may belong to a later age than the Trias. If the upper series of the Canadian (the possible Trias) represent not the Exeter sandstone, but that portion of the Red Beds removed by erosion where the Exeter sandstone now occurs in the Rio Cimarron, then the Exeter may be a younger formation—possibly the Trinity sandstone. In Mr. Hill's folio of the Texas Region he gives a "section showing the geology of the Texas region." This region embraces

[1] "Physical Geography of Texas Region," *U. S. Geol. Surv. Topographic Atlas*, p. 2.

[2] R. T. HILL, *Physical Geography of the Texas Region*, p. 3.

the exposures which I studied along the Canadian, and extends to within a few miles of the Rio Cimarron. According to Mr. Hill's section the Lower Cretaceous, consisting of the *Trinity*, *Fredericksburg*, and *Washita*, lies between the Red Beds and the Dakota. If Mr. Hill's section represents correctly the age of the formations in the Canadian valley, then the shales and possibly the Exeter sandstone must be of Lower Cretaceous age. But the shales, as I have already shown, are probably the same as the Dinosaur-bearing shales of the Purgatory. There is some probability therefore that the Morrison formation may be identical with some part of the Lower Cretaceous of the Texas region.

Correlation.—The key to the correlation of the shale formation is found in the Walsenburg area, Colorado. Mr. Hills[1] describes the Morrison of that region as a series of variegated shales, sandstones, and limestones lying between the Red Beds and the Dakota sandstone. According to his map the Morrison is found along the mountains near the western border of the Walsenburg quadrangle and in the canyons at the eastern extremity. The Morrison, as described in his folio, is identical in lithologic character and stratigraphic position with the shale formation described in this paper. In the Spanish Peaks area, bordering the Walsenburg area on the south,[2] the Morrison is also thought to be represented in the uplift at the Spanish Peaks. From the exposures mapped by Mr. Hills along the mountains it is but a few miles to the outcrops of the shale formation along the foothills previously described in this paper. The sedimentary formations, including the shales, are upturned a few miles west of the western boundary of the Spanish Peaks area, hence do not appear in the map of that region. There is little doubt that the shales which I have described as occurring as far south as Gold Creek, N. M., is a part of the southward continuation of the Morrison formation.

Starting again from the Walsenburg area, the Morrison occurs

[1] R. C. HILLS, *U. S. Geol. Surv.*, Walsenburg Folio, Colo.

[2] R. C. HILLS, *U, S. Geol. Surv.*, Spanish Peaks Folio, Colo.

beneath the Dakota in the canyon of the Huerfano River. In the next canyon to the east, the Apishapa, similar shales, and similarly placed, occur beneath the Dakota. Still further to the east and south, in the Purgatory and its branch canyons the same shale series occurs, bearing numerous Dinosaur bones of undoubted Morrison type. From thence southward to the Rio Cimarron and the Canadian the shales are lithologically and stratigrapically the same. It seems evident, therefore, that the shale formation throughout the region under consideration should be referred to the Morrison. It seems evident, furthermore, that the Morrison originally extended uninterruptedly over the entire region examined. Since no evidence of diminution in thickness was found, it is safe to assume that the formation extends eastward and southward beyond this area. Whether they extend to the south and east and merge into the undoubted Lower Cretaceous, as previously suggested, remains as yet undetermined.

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THE PREPARATION OF A GEOLOGIC MAP.

THE following paper is a discussion of certain factors influencing the quality of a geologic map; and an attempt has been made to formulate the conditions which must be fulfilled before a map can be considered satisfactory. Two important branches of the subject, however, are not treated: the drafting and the process work. The quality of both is closely dependent on the amount of money available for the preparation of any particular map, and therefore neither can be discussed in a general way. Disregarding these more purely mechanical factors, the value of a geologic map depends upon the accuracy and the precision of the field work; on the completeness with which certain data, both geologic and geographic, are presented on the maps; and on the care with which scale, colors, conventions, etc., are chosen so as to give the best results.

A section might, perhaps, have been devoted to a consideration of the ethical questions involved in the preparation and publication of a geologic map. The writer has, indeed, discussed certain of these points, but from the point of view of expediency rather than of abstract justice. The ethical code for the cartographer is simple; he should give due credit for work done by others; and he should frankly acknowledge doubt or ignorance. The first canon requires that both the geologic and geographic data should be properly credited; the second, that geologically unknown areas should be left blank, that doubtful boundaries should be distinguished from those accurately traced; and that, if possible, the location of actual outcrops should be indicated.

I. ACCURACY AND PRECISION OF FIELD WORK.

The map should show geologic boundaries as precisely as the geographic and topographic accuracy of the base will permit.

When, as frequently occurs, a geologic map falls below this

grade of accuracy, the fault is generally in the field work, and not in the map-drafting. Many geologists fail to realize in practice, though they may admit in theory, that geologic mapping on an atlas sheet is very different from mapping on a post-route map. It might seem hardly necessary to say that the geologic boundaries, when a contoured base is used, should be accurately fitted to the topography; but unfortunately evident violations of this rule are frequent. In one very recent instance a map, whose mechanical execution is admirable, is accompanied by structure sections which show that the geologic boundaries on the contoured map are in physically impossible positions.

Throughout much the greater part of the United States geologic mapping must be carried on in areas which have not as yet been mapped with any approach to accuracy. County, land-office, or post-route maps will be the only bases obtainable. In any inhabited area, roads are surveyed and mapped with tolerable accuracy long before any attempt is made to show drainage or relief. For this reason, in geologic mapping in a base known to be geographically inaccurate, boundaries and outcrops should be, when possible, referenced with respect to roads and road intersections, and not with regard to natural features. If thus referenced, these boundaries may be transferred to another base at any time, without necessitating the revision of the field work.

The accuracy of the field work is not a matter which interests the cartographer so much as its precision. If the field geologist has erred in determining the age or general relations of a certain formation, the cartographer cannot question the determination. He has, however, a right to ask that boundaries be traced and locations made with a certain degree of precision, a degree which will vary with the character of the base map used; and that the various elements of the manuscript map agree *inter se* (*e. g.*, that the areal mapping is not contradicted by the structure sections).

II. REQUISITE GEOLOGIC DATA.

Title.—The title of the map, omission of which is rarely permissible, should explain the character of the mapping (geologic,

outcrop, reconnaissance, detailed, etc.), and should also describe the area covered by the geologic coloring. As to wording, the title should be as concise as possible, and grammatically correct. such expressions as "Geologic map of the —— river," or "Geologic map of the —— limestone," should be avoided. It is frequently necessary to publish maps of areas which for some reason cannot be readily located or described in words, so that the title (unless made unreasonably long) cannot be made entirely satisfactory in regard to its geographic precision. In such cases at least one meridian of longitude and one parallel of latitude should be introduced and properly numbered, to serve as an aid in locating the area mapped.

Author and date.—The name of the geologist or compiler should be given on the map, together with the date. So far as the latter is concerned, for most purposes the year will be sufficient; occasionally a more precise statement will be advantageous. This date should in every case be the date of completion of the manuscript map; its date of publication will be fixed by other evidence.

Acknowledgments.— In the case of a compilation, if space be available, credit should be given on the map to the various geologists whose partial maps were utilized. If space is not available on the map itself, reference should be made to the publication in which these acknowledgments are made. Remissness in this respect, whether intentional or not, is unpardonable. Plate I of Monograph V, United States Geological Survey, (*Copper Bearing Rocks of Lake Superior*), is particularly detailed in its acknowledgments, despite its comparatively small size.

Legend.— The amount of detailed information to be given in the legend is governed by two considerations. The first is, of course, the amount of space available on the map. The second, on which sufficient stress is rarely laid, is the liability of the map to be separated from the text. Every convention used on the map must be explained in the legend; but the extent to which this explanation should be carried depends largely on the form in which the map is published. A map issued in a roll or pocket

will almost invariably become separated from the volume or paper which it is supposed to accompany; and the legend of a map published in that shape should accordingly be as detailed as possible. A map inserted as a plate is somewhat less likely to be used separately and the legend may be less detailed; while a map set in the text cannot well be separated from it and its legend may therefore be reduced to the briefest outline.

Boundary lines.—Every formation should be bordered by a definite boundary, unless transition or intergradation is meant to be shown. Except in this relatively infrequent case, it is not permissible to allow two colors or conventions to meet without an intervening boundary line. When possible, it is advisable to distinguish different grades of precision by the use of different conventional boundaries. For example, where the boundary has been traced in the field with a certain degree of precision, the separating line may be continuous; where the boundary is doubtful, or inferred, the line may be broken or dotted. Continuous lines indicating faults may be given double thickness, in order to distinguish them from continuous lines indicating precisely located boundaries,

Distinction of outcrops.— In detailed maps whose scale is sufficiently large to permit such treatment, precision is gained by distinguishing actual outcrops from areas whose geology is merely inferred. This distinction may be made by using for the outcrops either a pattern or a hachure or cross-lining under the color. The best examples of the latter method with which the writer is acquainted are to be found in Monograph XXXVI of the United States Geological Survey (*On the Crystal Falls Iron-Bearing District of Michigan*). In this volume, the practice is entirely consistent on the point in question, all its detailed geologic maps (Plates XVI, XVII, XVIII, XLIX, L, LI) distinguishing actual outcrops by means of cross-lining, disposed so as to show both location and size of these outcrops. Plate XXXI of Monograph XXXIII (*Geology of the Narragansett Basin*) distinguishes outcrops by means of cross-marks. Earlier publications on the Lake Superior region, both in monographs and in papers in the

Annual Report, have indicated actual outcrops, but the practice has not been general. It would seem that this distinction might profitably be made on maps included in the geologic folios, at least in those cases in which the geology of the area covered is complicated.

III. REQUISITE GEOGRAPHIC DATA.

Acknowledgments.—The geographic base should be credited and described, if possible, on the map itself; if the necessary description be too long for the space available, it should be contained in the textual discussion of the map. The value of a geologic map is greatly increased if the accuracy of its geography and topography can be estimated: and this is generally possible if the source whence they were derived be noted.

Scale.—Except in the case discussed in the next paragraph the scale should always be indicated diagrammatically on the map, by means of the familiar bar scale. The scale may, in addition, be indicated fractionally or verbally; allowance being made for reduction (if any) during reproduction. The shrinkage and expansion of paper due to changes in moisture are so great that these arithmetical or verbal statements of the scale are of little value; and they should never be used without a diagram.

In maps whose scale or area is so large that the effect of the earth's sphericity is appreciable, several meridians of longitude and parallels of latitude *must* be introduced and properly numbered, in order that the scale in different parts of the map be determined.

Contours.— If the base shows topography by means of contours, the datum plane and contour interval should be stated on the map.

Orientation.—When possible, the map should be so oriented with respect to the sheet on which it is printed that the north will be at the top. If this is not possible—and invariably if no parallels or meridians are introduced—the direction of a true north and south line should be indicated by the conventional arrow. In case the strike readings are quoted from the mag-

netic north, the declination of the needle should also be shown (the average for the district being taken) or stated verbally.

Projection.—In maps where scale or area is sufficiently large to render the information of value, the system of projection should be stated; or, better, it should be shown graphically by introducing a number of meridians of longitude and parallels of latitude. As noted under the discussion, in a previous paragraph, of the scale of the map, these meridians and parallels will serve a double purpose.

IV. CHOICE OF SCALE, CONVENTIONS, ETC.

Area of map and coloring.—The area covered by the map should not be larger than is necessary to illustrate the point under discussion. Whenever possible, the colors should be carried to the border of the map. Political divisions are rarely natural divisions; and it is therefore rarely advisable to stop the coloring abruptly at a political boundary, especially if the geologic value of the map can be increased by carrying the mapping into an adjoining political division.

Scale.—As the scale adopted directly affects the size of the map, the selection of the scale will frequently be affected by consideration of expense. Commonly, however, there will be room for choice, within certain limits; and in this case, or in rare instances where the question of expense may be disregarded, the selection of the scale will be subject to the following rules:

The scale should be sufficiently large to show all the geologic and geographic detail necessary. Curiously enough, this rule is rarely disregarded; the fault commonly committed being the adoption of too large a scale.

The scale should not be larger than is permitted by the degree of accuracy of the geologic field work, or by the geologic detail which must be shown. The degree of accuracy of the geologic field work will usually have been fixed by the scale of the field map on which the geologic observations were first plotted; and the published map, therefore, should not in general be on a larger scale than was this original field map.

Colors and conventions.—Whenever possible, the colors and patterns adopted by the United States Geological Survey should be adopted, for the sake of uniformity. Whether this be done or not, the maps issued by any one survey should be treated according to some one system. This is especially necessary when the maps so issued form a series, as in the publication of a number of county maps.

A formation should never be expressed by entire lack of color and pattern, as such a practice frequently leads to confusion. This, of course, refers particularly to black-and-white maps, as formations are rarely so treated on colored maps.

In small or local maps, particularly in such as are prepared for general use or to illustrate the distribution of economically important formations, the colors or conventions used for the different formations should be as distinct as possible. The smaller the areas to be distinguished, the greater will be the necessity for careful choice of colors or conventions, in order to obtain the greatest possible contrast.

In maps either of large scale, or covering large areas (in which case the geology will be of necessity much generalized), the general effect of the color scheme should be considered. In the allotment of colors and conventions to the different formations, it should be borne in mind that, the smaller the areas covered by any one formation, the brighter the color and heavier the pattern it will bear without seeming crude or obtrusive. As large maps are, in general, mounted and used as wall maps, a formation occurring mainly or entirely near the top of the map may be given a brighter color or more striking pattern than one in the middle or near the bottom of the map.

Patterns.—If patterns be used, with or without color, certain additional points must be considered. In the case of a formation occupying small areas, the pattern selected for that formation should bear some definite relation to the form and orientation of those areas. For example, a formation extended as a narrow belt should be given a pattern whose ruling is, as near as possible, at right angles to the general trend of the belt.

Experience has shown that, of the long list of patterns originally suggested for use, a certain few almost invariably fail to give good results in practice. Some of these are apparently poor, whatever paper is used; others fail only when the less highly surfaced papers are printed on. The last class are still serviceable for maps issued flat or in rolls; but can not be utilized with good results for folded maps, for which a highly surfaced paper is undesirable. Examination of a large series of maps on which patterns have been used will aid in determining which will be most effective in the special case under consideration.

In the preparation of this paper, the writer has made free use of the experience of this office, and has been greatly aided by the advice of Dr. F. J. H. Merrill. Maps issued by the United States Geological survey have been used as examples, in order to avoid the citation of maps published by the New York State Museum.

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THE NOMENCLATURE OF THE LAKE SUPERIOR FORMATIONS.

"THE Iron Ore Deposits of the Lake Superior Region," by Professor C. R. Van Hise, recently published in the *Twenty-first Annual Report of the United States Geological Survey*, is a most noteworthy contribution to Lake Superior geology. While especially valuable to mining men, for whom it was prepared, its references to stratigraphy are most interesting to geologists. In a footnote (p. 317) it is stated that the evidence upon which the geological succession is based will be fully given in a monograph upon the Vermilion District to be published later. While for the most part in accord with the author's stratigraphy, I do not agree with his nomenclature, and this paper is written with the hope that by discussion unanimity may be reached in this matter also. Owing to its importance, I here quote almost in full the footnote referred to above:

The foregoing papers render it unnecessary for me here to take up the general stratigraphy of the Lake Superior region. However, our work north of Lake Superior, in northeastern Minnesota and Canada, has upon two points modified our published conclusions as to succession and correlation. Those who compare this paper with earlier papers will note two important modifications. First, the Archean has heretofore been supposed to be composed wholly of igneous rocks; no sediments have been recognized in this division of the pre-Cambrian. The north-shore work, however makes it very probable that certain of the sedimentary iron-bearing formations must be included in the Archean. As examples of such are the productive iron formations of the Vermilion and Michipicoten districts. This modification is important from a theoretical point of view, since it will make changes necessary in my general definition of the Archean and of the Algonkian. The Algonkian has been defined to include all pre-Cambrian sedimentary rocks. The Archean has been defined to include all pre-Algonkian rocks, and has been supposed to contain igneous rocks only. These definitions must be modified so as to include in the Algonkian all pre-Cambrian series which are dominantly of sedimentary origin, or equivalent in age with those which are dominantly of sedimentary origin. The Archean must be defined

to comprise the rocks older than the Algonkian, which are dominantly of igneous origin, but which may include subordinate amounts of sediments. Recent work in northwestern Europe, and especially in Scotland, Scandidinavia, and Finland, where the ancient rocks are best exposed in Europe, shows that these modifications in the definitions of the Archean and Algonkian are also there applicable. The changes are quite in line with what might be expected; for in recent years no one feature in geological advance has been more significant than the sweeping away of sharp dividing lines between the various periods.

Second, the iron-bearing formations of the Vermilion and similar districts I have heretofore regarded as Lower Huronian. In placing these formations in the Archean I recognize three series in which productive ore formations are found, the Upper Huronian, the Lower Huronian, and the Archean.

The evidence upon which these modifications of my opinion concerning Lake Superior stratigraphy are based cannot be here presented in detail. It will be fully given in a monograph upon the Vermilion district, to be published later. In general it may, however, be stated that our work in the Vermilion district of Minnesota and on the Canadian side of the international boundary has convinced us that bands of sedimentary iron-bearing formations are interstratified with the upper part of the oldest series of the Lake Superior region, composed of greenstones, greenstone schist, and tuffs, although the thick productive belts of the Archean appear to rest upon the greenstones and greenstone schists.

Professor Van Hise here lends his weighty support to some views long held by others. It is admitted that true sediments occur in his old Basal Complex, though he does not carry this admission to its logical conclusion and attach the sediments to his Algonkian. Intrusive into these sediments are the granite gneisses of the Complex, a position held by Lawson,[1] Coleman[2] and others. Among these I now place Van Hise, for the Mona and Kitchi schists of Marquette containing banded jasper are pierced by the granites of the Basal Complex according to his description.[3]

The succession held by me is as follows:[4]

1. The Cambrian represented by the Lake Superior sandstone.

2. The Keweenawan.

[1] *Geol. Sur., Can.*, 1885 and 1887.

[2] *Reports Bur. of Mines, Ont.*

[3] *Mon. U. S. Geol. Sur.*, XXVIII, p. 186.

[4] *Cf. Am. Geol.*, XXVIII, 1901, p. 19.

3. The Animikie, mainly a sedimentary series, but locally containing great series of volcanic rocks.

4. The Upper Huronian, consisting mainly of sedimentary rocks.

5. The Lower Huronian, consisting of green schists and included sediments.

Besides these sedimentary series, the only proper factors in a time scale, there is an immense series of granites and gneisses largely of post-Upper Huronian age, which for convenience of reference have been given the old name Laurentian, a name applied to them when they were believed to represent the basement series.

This succession is almost identical with that given by Van Hise on page 316. The difference between us is largely one of nomenclature. Van Hise writes (p. 317):

> These series are called Huronian because they are believed to be equivalent to the Upper Huronian and Lower Huronian of the original Huronian district north of Lake Huron.

With this correlation I am not in accord. I believe the upper part of the original Huronian to be the equivalent of Van Hise's Lower Huronian, and the original Lower Huronian to be included in his Archean. If this can be substantiated, I have no doubt Professor Van Hise will view my nomenclature favorably, for no one is more anxious than he to recognize the work of Logan and Murray, the founders of the Huronian.

In 1858[1] Logan gave the name "Huronian" to the copper-bearing rocks north of Lake Huron, the distribution of which was being worked out by his assistant, Murray. In 1863[2] he gave a summary of the previous annual reports, and this may be fairly taken as representing his mature views. Detailed sections are given from the Sudbury, Michipicoten, and Mississaga districts. The rocks are mainly sediments, but interstratified with them are beds of amygdaloidal greenstone. Intrusive greenstones and granites are also recognized.

Two slate conglomerates were described separated by a

[1] *Rep. Geol. Sur., Can.*, 1857. [2] *Geol. of Can.*, 1863, pp. 50–66.

narrow band of limestone. These were practically alike in every particular and Murray found himself unable to distinguish them where the limestone was lacking.[1] The Upper Conglomerate carries occasional pebbles of the limestone when near it, but usually none are to be found. The limestone band as shown in Murray's map is largely conjectural, the outcrops being very few. It seems probable that the break between the two conglomerates is not of great significance and that it would be well not to attempt a separation of them.

Many geologists have argued for a division of the Huronian, though they have not agreed on the horizon. Alexander Winchell[2] places the break at the top of the Lower Slate Conglomerate. Pumpelly and Van Hise[3] place it above the limestone band. The important break must, however, lie much lower. Pebbles of banded jasper and hematite occur in the Lower Slate Conglomerate, in great abundance in places, and must have been derived from some lower sediment. Logan's white quartzite often becomes a conglomerate and is evidently only a phase of the Lower Slate Conglomerate. Excepting the chloritic slates we have, accordingly, in all the lower part of the Mississaga Huronian area evidence of the existence of a lower sediment. The probable occurrence of this banded jasper was recognized by Logan himself, though outcrops were not discovered. This lower conglomerate with jasper and chert pebbles thus becomes of the greatest value in working out Lake Superior stratigraphy, a fact emphasized by Coleman in a paper on the subject.[4] Logan also recognized its value, and correlated slate conglomerates in the Temiscaming, Sudbury, Mississaga, Batchawana, and Michipicoten districts. In describing the Doré series in the last district he mentions[5] pebbles of a "chert-like stone," and near Batchawana Bay jasper conglomerate was found. In maps of both these regions there were included within the Huronian, rocks which are now recognized as the source of the jasper and

[1] *Rep. Geol. Sur.*, 1858, p. 94.

[2] *Bull. Geol. Soc. Am.*, II, 1891.

[3] *Am. Jour. Sci.*, III, 1892, p. 42.

[4] *Rep. Bur. of Mines, Ont.*, 1900, pp. 182–86.

[5] *Geol. Can.*, 1863, p. 54.

chert pebbles. In the Temiscaming region, also, banded jaspers, which are the source of the pebbles in the conglomerate, have been found within the area described by Logan as Huronian. Near Sault Ste. Marie banded quartz has been found within the Huronian area.[1]

There can be no doubt that Logan in 1863 included within his Huronian two series — the one typically represented by the banded jaspers, the other by the slate conglomerate and the jasper conglomerate. This has been uniformly followed from that time forward by all Canadian geologists and by many American, the vertical green schists and their interbedded banded jaspers being considered Lower Huronian. These schists have also been mapped as Huronian in nearly every case by the Canadian Survey. It is true that Lawson, in his reports on the Lake of the Woods[2] and of Rainy Lake, describes similar rocks as Keewatin, doubtfully correlating them with the Huronian north of the Georgian Bay. He recognizes, however, their resemblance to those of the Michipicoten area, a conclusion with which I agree.

The lowest rocks at Michipicoten are greenstones, often ellipsoidally parted, and volcanic tuffs. Interbedded with the latter are cherty iron carbonates, pyritic quartz rocks, ferruginous cherts, and ore bodies. Into these two are numerous intrusions of greenstone and granite. Above lies a slate conglomerate. The resemblance to the Ely greenstone, Soudan iron formation, and Ogishke conglomerate as described by Van Hise[3] is very close. The similarity of the two regions was pointed out by Coleman and Willmot in a paper published in 1899,[4] and it is recognized by Van Hise in the present paper (p. 411).

These schists and interbedded ferruginous sediments have, however, always been considered as Huronian or Keewatin. I see no reason for abandoning the term Lower Huronian for

[1] *Rep. Bur. of Mines*, 1901, p. 187.

[2] *Geol. Sur., Can.*, 1885, I, and 1887, III.

[3] *Iron Ore Deposits of Lake Superior*, p. 402. [4] *Rep. Bur. of Mines, Ont.*

these earliest sediments. Because of the impossibility of separating the sediment from the inclosing greenstones and green schists except on very large scale maps, both will usually be mapped together. This must also be the case for many years over vast areas of Canada until the regions become more accessible. For this reason I doubt the advisability of attempting the separation of the volcanics and sediments except in limited areas of economic value. Here each would be given formational names, just as Van Hise has done with the Ely greenstone and the Soudan iron formation. In other places the volcanics and eruptives will take the name of the sediment with which they are associated. The lowest sedimentary series of the Lake Superior region is the Lower Huronian. These sediments were included in the areas mapped as Huronian by Logan in 1863, and, although not actually found in place by him, were recognized from their fragments, and to him should be given the credit. These rocks have always been mapped as Huronian by the Canadian Survey.

For these reasons, Lower Huronian is to be preferred to Archean in describing these rocks. Failing Lower Huronian, Keewatin should be adopted, for it too has priority over Archean as used in this connection.

If Lower Huronian is to be substituted for Archean it follows that Upper Huronian would properly replace Van Hise's Lower Huronian. Van Hise correlates (p. 411) the Ogishke conglomerate with the Doré conglomerate, and Logan considered this the equivalent of his Lower Slate Conglomerate. N. H. Winchell[1] and Alexander Winchell[2] both correlate the Ogishke conglomerate with Logan's slate conglomerate. With these correlations I agree on lithological grounds and because of the sequence all around the lake. This may possibly be proved, or at least supported in another way. Coleman has shown, in a paper already referred to,[3] the wide distribution of the slate conglomerates, and that all carry jasper or equivalent

[1] *Sixteenth Ann. Rep. Minn. Geol. Sur.*, 1887, pp. 12–40.

[2] *Ibid.*, pp. 145–71. [3] *Rep. Bur. of Mines, Ont.*, 1900.

pebbles. Barlow has shown[1] that, in the Temiscaming region, the granite-gneisses are in eruptive contact with this conglomerate. I have shown[2] that Murray recognized the eruptive character of the gneiss in connection with his slate conglomerate, though he attempted to explain the facts by faults. I have also shown[3] that at Michipicoten the schist conglomerate is pierced by granite-gneiss. Lawson[4] shows in his Lake of the Woods and Rainy Lake reports that the granite-gneisses are in eruptive contact with the schist conglomerates of his Keewatin.

We have thus for eight hundred miles across Ontario: (1) a schist conglomerate carrying pebbles of jasper and chert; (2) large areas of granite-gneiss in eruptive contact with it.

It is, of course, possible that these eruptions did not all take place at the same period, but from their magnitude and close connection throughout the whole region it is probable that they did. Taken with the occurrence of a conglomerate carrying such peculiar pebbles as jasper, it may almost be considered proved that all are of the same age. For this reason, in addition to those given above, the original Upper Huronian is considered the equivalent of Van Hise's Lower Huronian,

It follows that the Animikie (and so the Mesabi and Penokee) is younger than the Huronian. This was Logan's position[5] who called the Animikie the lower group of his upper copper bearing rocks. McKellar[6] held on lithological and structural grounds that the Animikie was later than the Huronian. Lawson[7] points out that the conglomerates of his Upper Kaministiquia come out close to the shores of Thunder Bay and form the basement upon which the undisturbed Animikie rocks rest with strongly marked unconformity. Lawson's Upper Kaministiquia I consider Upper Huronian. They are included in the vertical schists which are cut by the eruptive granite-gneisses.

[1] *Geol. Sur., Can.*, X, p. 91, I.
[2] *Am. Geol.*, XXVIII, 1901, p. 18.
[3] *Ibid.*, p. 16.
[4] *Am. Geol.*, VII, 1891, pp. 320–27.
[5] *Geol. of Can.*, 1863, p. 67.
[6] *Trans. Roy. Soc., Can.*, V, 1887.
[7] *Am. Geol.*, VII, 1891.

In the vicinity of Port Arthur I have found greenish schist with included ferruginous sediments, and also conglomerates carrying pebbles of the first. Both of these have highly inclined dips and have granite-gneiss in eruptive contact with the first at least. The lower series has numerous beds of pyritic quartz rock exactly like the beds in the lowest sediments at Michipicoten. Clearly these two series correspond to the Lower and Upper Huronian, as above defined. Overlying both, and also the granite-gneiss with very gentle dip is the Animikie series.

That the Animikie is later than the Upper Huronian or "Original Huronian," as it is often called, may be shown in several ways:

1. Stratigraphically it is the third series of sediments upwards from the bottom of the geological column in the Lake Superior region—the Upper Huronian is the second.

2. Lithologically, the two series are quite different, and so presumably are of different age. There is very little conglomerate at the base of the Animikie—in the Huronian the quartzites, slate conglomerates, and jasper conglomerates are of great thickness. The oolitic jaspers found in the Animikie are quite absent from the Huronian. The shales, so important in the Animikie, are almost unknown in the Huronian. The laccolitic sills of the Animikie are lacking in the Original Huronian.

3. Structurally, the two series are usually said to be alike in that both lie flat and undisturbed. While this is quite true of the Animikie, it is only partially true of the Huronian north of the Georgian Bay, and is untrue of the Upper Huronian about Batchawana and Michipicoten. Coleman[1] and Murray[2] have described cases of vertical dip within the so-called Original Huronian, and others have been observed by myself. These seem to occur around the outer portion of the Huronian basin, and more gentle dips obtain in the central part. Evidently the Huronian has been subjected to forces which the later Animikie has escaped.

4. Assuming that the large areas of eruptive granite-gneisses

[1] *Bur. of Mines, Ont.*, 1901, p. 189. [2] *Geol. Sur., Can.*, 1858, p. 95.

in the Lake Superior region are of the same age, we find that the Upper Huronian has in many cases been pierced by them, but that the Animikie always overlies them.

The conclusion seems inevitable that the Animikie is later than the Upper Huronian. If this is accepted, or if the Upper Huronian is accepted as the equivalent of Van Hise's Ogishke Conglomerate (his Lower Huronian), or if Lower Huronian is accepted as a preferable term for Archean Schist, if any one of these propositions is accepted as proved it seems to me the others should follow.

The succession in Lake Superior would thus be as follows:

Cambrian.
Keweenawan.
Animikie.
Upper Huronian.
Lower Huronian.

It may be urged that because of the enormous time break between the Lower and Upper Huronian, as here defined, the same name should not be applied to both systems. Providing that it is recognized that the terms are descriptive of systems, not of formations, it seems to me that they are quite as appropriate as Lower and Upper Marquette, Lower and Upper Cretaceous, etc. Moreover, in the reconnaissance work in the immense unsettled districts north of the great lakes, it is a distinct advantage to have a general word like "Huronian" to embrace the two systems which are easily separated from the remaining Archean, but are not easily separated from each other. Many areas have been mapped by the Canadian Survey as Huronian, which may or may not contain both systems. That will require more detailed work when the regions become more accessible.

There remains the question of a term of systematic value to designate the pre-Cambrian series. Should they be called Archean, Algonkian, or something else? The Lower and Upper Huronian, and those vast areas of eruptive granite-gneisses, which are mainly of post-Upper Huronian age, undoubtedly

represent the old Laurentian and Huronian to which the term Archean was applied by Dana. The Basal Complex to which Van Hise restricted the name when he introduced the term Algonkian, no longer exists. The sedimentary part, with the accompanying volcanics, is in this paper called Lower Huronian. The eruptive granites and gneisses are at least post-Lower Huronian if not post-Upper Huronian in their final consolidation, and must be included with one or the other. There remains nothing below the Lower Huronian to which the term Archean is applicable except the theoretical original crust as yet undiscovered. On the other hand, the continued application of Archean to the rocks known as Huronian and Laurentian, as originally given and as subsequently continued by many, would seem most appropriate. A. B. WILLMOTT.

STUDIES FOR STUDENTS

BASELEVEL, GRADE AND PENEPLAIN.

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Thesis of this essay.—The attention given during the last fifty years to the processes and results of land sculpture has naturally resulted in the introduction of various new terms, three of which stand at the head of this article. It is desired to point out that too many meanings have been attached to the first term, "baselevel," and that some of them should be transferred to the other two, "grade" and "peneplain."

The original meaning of "baselevel."—Although the control exerted by sea level on river action has long been recognized, the importance of the control was more generally perceived by American students of geology when it was explicitly formulated in the term "baselevel" by Powell in 1875. The term soon became so popular, especially with American writers, that a

divergence of meaning has arisen with regard to it. It is therefore proposed to trace its history, with the hope of inducing geologists and geographers to use it in a somewhat restricted sense. It will be spelled here as a single word, disregarding the separation into two words by some authors and the hyphen of others, except in the first quotation.

Powell's original definition of "baselevel" is as follows, the parenthesis being in his text:

> We may consider the level of the sea to be a grand base level, below which the dry lands cannot be eroded; but we may also have, for local and temporary purposes, other base levels of erosion, which are the levels of the beds of the principal streams which carry away the products of erosion. (I take some liberty in using the term level in this connection, as the action of a running stream in wearing its channel ceases, for all practical purposes, before its bed has quite reached the level of the lower end of the stream. What I have called the base level would, in fact, be an imaginary surface, inclining slightly in all its parts toward the lower end of the principal stream draining the area through which the level is supposed to extend, or having the inclination of its parts varied in direction as determined by tributary streams.) Where such a stream crosses a series of rocks in its course, some of which are hard, and others soft, the harder beds form a series of temporary dams, above which the corrasion of the channel through the softer beds is checked, and thus we may have a series of base levels of erosion, below which the rocks on either side of the river, though exceedingly friable, cannot be degraded (1875, 203, 204).

"Baselevel" as thus defined seems to include three ideas. First, the grand or general baselevel for subaerial erosion is the level of the sea; second, a baselevel is an imaginary, sloping surface which generalizes the faint inclination of the trunk and branch rivers of a region when the erosion of their channels has practically ceased; third, local and temporary baselevels are those slow reaches in a river which are determined by ledges in its course further down stream.

There is some reason for thinking that Powell's intention may have been misunderstood with respect to the first and third of these ideas. The first, "the level of the sea," may have referred only to the actual area of the sea, and not to an imaginary extension of the sea level or geoid surface under the lands.

The third certainly referred to the faintly sloping reach of a river, and not to a level surface passing through the ledge of hard rock with respect to which the reach is worn down, although this latter meaning has become popular. The following citations will show that most writers seem to be agreed that baselevels may be local or temporary as well as general, but that there is no prevalent agreement as to the definition of either the general or the local baselevel.

Definitions of "baselevel" by various writers.—The following authors adopt the first of the above meanings. Gilbert writes:

> The land cannot be worn down below the level of the ocean. Geologists express this law by saying that the ocean is the "baselevel of erosion" (1896, 575).

Campbell says:

> If the streams are in their old age, the surface of the land will constitute a peneplain, and in their extreme old age, this peneplain will approach very closely to baselevel (665).

Tarr writes to the same effect:

> In no part of the valley can the stream cut below the sea level, or below *baselevel*, as it is called (265).

Russell quotes Powell, as if adopting his definition, but concludes that:

> The real baselevel toward which all streams are working is the surface level of the sea. . . . When a stream has lowered its channel nearly to baselevel, downward corrasion is retarded, but lateral corrasion continues. . . . The ultimate result of erosion is to reduce a land area to a plain at sea level (47–48).

Finally, Powell may be quoted again as follows:

> The baselevel of a plain is the level of the surface of the sea, lake or stream, into which the waters of the plain are discharged (1895, 34).

The second idea under the term "baselevel"—that of the imaginary undulating surface—does not appear to have been adopted by any of the many writers whose works I have looked over. It is perhaps on account of the elaborateness of this second meaning that it has not come more generally into use. Its partial adoption, however, is indicated by the following

extracts. It should be noted that nearly all the writers here cited imply that, after baselevel is reached by a stream, downward corrasion ceases.

McGee describes the streams of the coastal plain at about the head of Chesapeake Bay as "at baselevel" (1888, 617).

Darton says, when describing the dissection of the Piedmont plateau of Virginia:

> As the cutting reached baselevel a series of wide terraces were cut (584).

Winslow writes:

> The streams of the prairie country [in Missouri] . . . . have, in large part, reached baselevel, and are developing meander plains (310).

Fairbanks states that in southeastern California:

> Erosion has reached an advanced stage with the production of excellent examples of baselevelling. . . . . One of the best examples . . . . is the western portion of a granite ridge lying south of the El Paso range. . . . . It is bordered by long gentle slopes of gravel and bowlders, which extending upward into the shallow cañons reach almost to the summit. Viewed from a distance of ten miles but little of the mountains appears to project above the plane of deposition (70).

Salisbury's statement is as follows:

> The time necessary for the development of such a surface is known as a *cycle of erosion*, and the resulting surface is a *baselevel plain*, that is, a plain as near sea level as river erosion can bring it. At a stage preceding the baselevel stage the surface would be a *peneplain*. . . . . It is also important to notice that when streams have cut a land surface down to the level at which they cease to erode, that surface will still possess some slight slope, and that to the seaward. Along the coast, a baselevel is at sea level. A little back from the coast it is slightly higher, and at a greater distance still higher. No definite degree of slope can be fixed upon as marking a baselevel. The angle of slope which would practically stop erosion in a region of slight rainfall might be great enough to allow of erosion if the precipitation were greater. . . . . The Mississippi has a fall of less than a foot per mile. . . . . A small stream in a similar situation would have ceased to lower its channel before so low a gradient had been reached (1898, 73, 79).

J. Geikie writes:

> Running waters will continue to deepen their channels until the gradient by the process is gradually reduced to a minimum and vertical erosion ceases. The main river will be the first to attain this baselevel — a level not much above that of the sea (47).

Marr does not use the term "baselevel," but says instead:

> A river which has established equilibrium . . . . is said to have reached its base-line of erosion, and no further work of erosion or deposit can occur until the conditions are changed (84).

Dryer states:

> The lower Mississippi has reached its baselevel, or the lowest level to which its current and load will permit it to reduce its bed. . . . . In the lower reaches of a river the valley is soon cut down to baselevel, where the slope is gentle and the current too slow to carry the full load of sediment it receives. Deposition occurs and downward corrasion ceases (79, 154).

Powell makes the following statement in a discussion of reaches and rapids:

> The slow reach is a baselevel, like that of a lake, below which the banks and hills on either side cannot be degraded (1894, 35).

Various other definitions, more or less aberrant from the original and discordant with each other, are found in the following citations:

Dutton took baselevel to be a condition:

> The condition of baselevel is one in which the rivers of a region cannot corrade. As a general rule it arises from the rivers having cut down so low that their transporting power is fully occupied, even to repletion. . . . . The recurrence of upheaval terminates the condition of baselevel (224, 225).

According to Willis baselevel is a slope:

> A baselevel is the lowest slope to which rivers can reduce a land area (1895, 189). The ideal lowest possible slope, which is called a baselevel, is perhaps rarely reached (1900, 27).

Hayes makes baselevel a mathematical plane:

> The term baselevel, synonymous with baselevel of erosion, is [here] restricted to Powell's original use . . . . the general baselevel being sea level. There may be an indefinite number of *local* baselevels in any region, each being determined by the outlet of the stream whose drainage basin is considered; but only one *general* baselevel. . . . . It should be clearly understood, then, that a baselevel is not a topographic form, but a mathematical *plane*, which may or may not, and generally does not, coincide with a land surface (21).

When describing erosion by rivers, Scott writes:

> A stage must sooner or later be reached when the vertical cutting of the stream must cease. This stage is called the baselevel of erosion or regimen

of the river, and it approximates a parabolic curve, rising toward the head of the stream (98).

Rice makes the following statement:

The condition of balance between erosion and deposition [by rivers] has been called by Powell the condition of baselevel (140).

Brigham writes as follows:

A baselevel is a plane to which denudation must reduce a stably poised land mass, and below which denudation cannot take place. The plane is that of the ocean surface . . . . The great river first cuts its bed close to the sea level, and we say that a portion of the valley is reduced to baselevel. It lacks a little of it, but the difference is so small that we neglect it. Gradually the valley widens, and the baseleveled strip extends up the stream toward the heart of the country (281).

Cowles gives a definition of "baselevel" which taken literally gives it the meaning of a process:

Denudation of the uplands and deposition in the lowlands results in an ultimate planation known as the baselevel (178).

The derivative use of baselevel as the name of a worn-down land surface does not seem to be so common now as it was some ten years ago. A few examples will here suffice.

Keith made frequent use of "baselevel plain," or simply "baselevel," as the name for a surface that had been reduced to faint relief, even though now uplifted and more or less dissected. He discusses the "considerable variation in the altitude of different parts of the baselevel" or old Tertiary land surface in the Catoctin region district of Virginia (373). He mentions "hill tops marking the dissected baselevel" of the Shenandoah valley (374). The term seems to be applied in at least one instance to a peneplain in saying:

It needs but little study of this baselevel to discover considerable inequalities in its surface (369).

Diller made equally free use of "baselevel plain" and of "baselevel" in his account of an ancient surface of erosion in northern California. He states that "the western edge of the baselevel, where it enters the mountains, has an altitude of 2,600 feet," and on a later page he suggests two ways in which the "deformation of the baselevel may be studied" (406, 430).

Kümmel writes of the "long erosion which resulted in the Cretaceous baselevel" of Connecticut (379).

Willis says:

> The tendency is in time to reduce the land to a gently sloping plain, which extends from the sea to the headwaters of the rivers. Such a plain is called a *baselevel*. . . . . A surface, which is almost, but not quite, a baselevel, is called a *peneplain* (1895, 188, 189).

Hill describes a persistent bench near Panama as:

> Representing an ancient baseleveled plain, which will be described as the Panama baselevel (197).

An essay by Van Hise describing a "baseleveled plain" is entitled "A Central Wisconsin Baselevel" (57).

I have had a small share in a similar use of "baselevel;" for example:

> The general upland surface of the Highlands [of New Jersey] is an old baselevel, in which valleys have been cut in consequence of a subsequent elevation (1889, 20: see also Davis and Wood, 384).

A review of the above citations, whose number might be greatly extended, shows that "baselevel" is given very different meanings by different writers. These meanings are: an imaginary level surface in extension of that of the ocean (the convex geoid surface); an imaginary mathematical plane; an imaginary surface sloping with the mature or old streams of its area; the lowest slope to which rivers can reduce a land surface; a level not much above that of the sea; a slow reach in a stream; a condition in which rivers cannot corrade or in which they are balanced between erosion and deposition; a certain stage in the history of rivers when vertical cutting ceases and their slope approximates a parabolic curve; an ultimate planation; and a plain of degradation.

Limitation of the meaning of "baselevel."—The diversity of the above definitions may be better perceived when it is noted that they are expressed in terms of very unlike quantities: imaginary surfaces, level, plane, or warped; a low slope; a part of a river; a condition of river development; a stage in river history; an ultimate planation; and an actual geographical form. It is evi-

dently desirable to associate "baselevel" with at most only a few of these meanings, preferably with only one; and to leave the others unnamed or to associate them with other terms. It seems to me advisable to limit "baselevel" to the first meaning, an imaginary level surface, and to define it simply as the level base with respect to which normal subaerial erosion proceeds; to employ the term "grade" for the balanced condition of a mature or old river; and to name the geographical surface that is developed near or very near to the close of a cycle, a "peneplain," or "plain of gradation." The following paragraphs may make the need of this discrimination clearer.

A full understanding of the development of land forms can be gained only by tracing the progressive changes of a generalized example from the initial stage through the various sequential stages to the ultimate stage of an ideal geographical cycle. This problem is encountered in an elementary form at the beginning of the study of land sculpture in physiography or geology, and at the very outset it is necessary to make definite and simple statement regarding the limit with respect to which the processes of normal subaerial erosion (weather and streams, without significant aid from wind or ice) may act. If the limit is defined in terms of the slopes that the streams of the region will have gained when they have reached a maturely balanced condition, the definition will be of no service to beginners; indeed, a limit thus defined is elusive and difficult of conception even by experts. The limiting surface is certainly of so great importance to the beginner that it must be briefly defined for him in terms of known factors, and the definition thus framed should remain serviceable through all later study. These conditions are satisfied when the beginner is told that the limit of subaerial erosion is the "level base" or "baselevel," drawn through a land mass in prolongation of the normal sea level surface. The fact that rivers erode their channels near their mouths below sea level and that special processes of erosion (winds and glaciers) may work below sea level, does not invalidate the general statement at the opening of the whole discussion; but these special condi-

tions must be explicitly considered later, especially those concerning glacial erosion. It suffices at first to recognize that in the ideal undisturbed cycle of normal erosion the baselevel must be more and more closely approached as time is extended.

This definition of "baselevel" as a level base certainly has the advantage of being easily conceived. Once conceived in the study of the ideal cycle, it needs no modification so long as the relative attitude of land and sea remains fixed. If the land rise or fall with respect to the sea, the baselevel takes a new position within the land mass, and further progress of erosion is then continued with respect to the new limit.

As the study of the cycle advances it becomes desirable to speak of various local or temporary controls of erosion: a rock ledge or a lake on a river course, the central basin of a dry interior basin either above or below sea level, the surface of a lake in such a basin. Nothing can be simpler than to imagine a level surface passing through any one of these controls, and rising or sinking as the control rises or sinks; and such a surface is naturally called a local or temporary baselevel. With the enlargement of conceptions that is required when the aggradation of depressions is considered at the same time with the degradation of elevations, Powell's more general term, "gradation," may replace "erosion;" the merit of this substitution will appear more fully in the following pages.

In view of the importance appropriately allowed to the idea of the level base with respect to which the erosion of valleys by rivers must proceed, it is curious that earlier writers did not give more explicit attention to it; but as far as I have read, they were so largely occupied with controverting the various older theories of the origin of valleys that it did not occur to them to give special name to limiting surface of erosion. Their understanding of the important principle here involved is to be read rather between the lines than in explicit statements. For example, Greenwood, in his curious book on *Rain and Rivers*, almost as remarkable for its admixture of jokes and polemics

as for its many admirable expositions of rain and river work,[1] contains the following account of the problems here considered:

> Suppose a barrier of rock to run across any valley or river bed; when the bed of the valley or river on the upper side of the barrier has been worn down to a horizontal level with this barrier, it can *not* go lower. . . . . But as the barrier is cut through, the bed of the valley or river will be deepened *backward*, or from below upward, or towards the hills. . . . . The passage of the detritus and soil from the inclined upper parts of valleys is checked in the horizontal lower parts of valleys, and soil accumulates there. This is the origin of alluvial plains; and a river of any size, or any rapidity, may, at any distance from the sea, have *patches* of alluvial plain, where no lakes have ever been; that is, above every rapid or accidental barrier of hard ground. . . . . The only difference in the laws for the growth and gradient of these patches from those which regulate the growth and gradient of the plain at the level of the sea, is that they have no *increasing* cause for rising equivalent to the *forward* lengthening of the delta of the lower alluvial plain. These flat alluvial patches may be seen even in torrents, sometimes reaching from one cascade to the other. . . . . It is easy to perceive that these patches must be liable to constant change. They must be perpetually shortened by the recession of the lower barrier, and lengthened by the recession of the upper one. . . . . These principles are eternally at work on all valleys, from the smallest to the largest" (174–176).

The use of "horizontal" in describing the lower parts of valleys is curiously inexact in contrast to the keen recognition of the difference between what we should now call local and general baselevels, and of the aggradation of a flood-plain on account of the "forward lengthening of the delta."

The balanced condition of rivers.—Turning now more particularly to the problem of river action, we find that the balance between erosion and deposition, attained by mature rivers, introduces one of the most important problems that is encountered in the discussion of the geographical cycle. The development of this balanced condition is brought about by changes in the capacity of a river to do work, and in the quantity of work

[1] Here is a characteristic illustration of Greenwood's mixture of sense and nonsense: "The very soil on which we tread . . . . may be said to be on its road from the hill to the sea. . . . . No drop of rain *runs* an inch on the surface of the earth without, as far as it goes, setting some soil forward on its road to the sea, and it won't run back again. No return tickets are given. It will wait there, and go on by the nex-*t-rain*" (105).

that the river has to do. The changes continue until the two quantities, at first unequal, reach equality; and then the river may be said to be graded, or to have reached the condition of grade. This condition cannot be understood without rather careful thinking on the part of the expert as well as of the tyro. The idea of grade is not of almost axiomatic simplicity, like the idea of baselevel; its meaning must be gradually elaborated as it is approached. Moreover, a graded river does not maintain a constant slope; it changes its slope systematically with the progress of the cycle: but before taking up this element of the discussion a few paragraphs may be given to the consideration of "grade," as a common word used in a technical sense.

It should be noted in the first place that it is a condition of river development, not a surface, nor a stage, nor a form, for which the term "grade" is to serve as a name. The condition of grade must not be confused with the limiting under-surface of erosion, with respect to which the graded condition is developed; the name for this surface is "baselevel." Nor must it be confused with the stage in the history of river development in which the graded condition is reached; "maturity" is the name for that stage; but it may be noted in passing that the graded condition persists all through the old age as well as the maturity of an uninterrupted cycle. "Grade," meaning a condition or balance, must not be confused with the same word used in another meaning, namely, the slope or declivity of the river when the graded condition is reached; for "grade" meaning slope, varies in place and in time, while "grade," meaning balance, always implies an equality of two quantities. In fine, grade is a condition of essential balance between corrasion and deposition, usually reached by rivers in the mature stage of their development, when their slopes have been duly worn down or built up with respect to the baselevel of their basin.

There can be no question that the balanced condition of mature and old rivers deserves a name. It was to this condition that Powell called attention in his original discussion of land sculpture, and to which he devoted one of the meanings of

his term "baselevel." A name had already been suggested for the balanced condition by various writers, who called it the "régime" or "regimen" of rivers, while the slope of a river under this regimen was called its "*penté d'équilibre*" by Dausse and the "*Erosions-Terminante*" by Philippson (1886, 71.) But (1857, 759) "regimen" may be better used as meaning the rule of river action under which the balanced condition is developed and maintained; while "slope of equilibrium" may be taken as a descriptive phrase, too cumbersome for ordinary or frequent use, but essentially synonymous with "graded slope." "Baselevel" seems at best a very inappropriate name for a condition in which the idea of slope is essential; and when another and equally important use is made of this excellent word, its employment as the name for the balanced condition of rivers is all the more unsatisfactory. "Grade" is the most satisfactory term for the balanced condition or state of equilibrium of rivers on several grounds, in spite of certain objections that may be urged against it. Let us consider the objections first.

Origin and use of the term "grade."—One of my correspondents has objected to "grade" because, in the sense here adopted, the word means, etomologically, a step and not a slope. This objection seems to me of small value on account of the freedom with which new meanings are given to old roots. Language does not grow by rule but by use; and use has decreed that one meaning of the English word "grade" shall depart somewhat from the meaning of its Latin ancestor. The chapter on "Transference of Meaning" in a work on *Words and Their Ways in English Speech*, by two of my colleagues, Professors Greenough and Kittredge, may be consulted to advantage in this connection.

Another correspondent objects because the word "grade" is already in common use, meaning among other things, a slope, and the ratio of the vertical to the horizontal in a slope; but as a matter of fact no practical inconvenience has arisen on this account. The context suffices to indicate which one of the several meanings of the word is intended. Moreover, if we

should endeavor to escape the criticism of Scylla, by making up a new technical term in order to avoid the technical use of a common word in a new meaning, we should be met by the objections of Charybdis, who maintains that "every new technical term is a positive detriment to science." The objections to "grade" seems to me far outweighed by the many points in its favor, which may now be reviewed.

In favor of the term, it may be noted first that "grade," like "baselevel," is of a convenient form, ready for use as noun, adjective, and verb, after the handy fashion of the English language in many other cases. In the second place, the sense of the verb "grade," as employed by engineers (to prepare, by cutting and filling, a smooth bed of gentle slope for a railroad or other line of transportation), is closely analogous to the meaning here advocated for the verb "grade" as used by geologists and geographers: a river grades its course by a process of cutting and filling, until an equable slope is developed along which the transportation of its load is most effectively accomplished. In the third place, "grade" lends itself admirably to the formation of such terms as "degrade," "aggrade," and "gradation;" "degrade," in the sense of to wear down, has been in use for some time by geologists; "aggrade" is an excellent addition to our terminology, proposed by Salisbury (1893, 103) in the sense of building up; while "gradation" is Powell's term for the general process of wearing down elevations and filling up depressions, in the production of lowland plains (1895, 30). Finally, the word has already made a beginning towards acquiring a useful place in scientific writings.

The use of "grade," in the sense here advocated, was almost reached by Gilbert in his description of hills of planation, covered with stream gravels: "The slope of the hill depends on the grade of the ancient stream, and is independent of the hardness and dip of the strata" (1877, 130); and again in his account of how a river "tends to establish a single, uniform grade," and "an equilibrium of action" (1876, 100). It was in consequence of a suggestion from this philosophical writer that I introduced

"grade" as a substitute for various paraphrases in my own work in 1893 (1894, 77).

McGee considers the control of the balanced condition of rivers under the "law of river gradation" (1891, 265).

Mill uses "grade" as a verb, essentially in the sense here advocated: "Ultimately the river grades its course and flows uniformly along a uniform slope" (56).

Gannett has adopted "grade" as a technical term in Folios 1 and 2 of the *Topographic Atlas of the United States*. In the first he writes:

> There finally comes a time when the river ceases to erode, or rather, it deposits as much as it erodes. . . . . A river is then said to be graded.

In the second, a special sheet with explanatory text is devoted to "A Graded River," the example chosen being the lower Missouri:

> At this stage the lower portion of its [a river's] course has been eroded to almost as low a stage as possible, and its slope has become very slight, so that its cutting power is trifling. This part of the stream is said to be "graded."

Johnson uses "gradation" as involving both degradation and aggradation, and as producing a "graded slope," a slope of "equilibrium easily disturbed, yet constantly maintained" (620).

"Grade" may therefore be regarded as having already gained recognition in the sense here advocated, as a replacement of one of the meanings of "baselevel."

There remain to be considered several reasons in favor of giving different names to the limiting base of sub-aerial erosion, and to the balanced condition in which rivers spend most of their lives while approaching the limit of their work. The first reason is based on the persistence of the base level surface all through the cycle, without change from its initially complete extension, in contrast to the gradual introduction and slow extension of the condition of grade during the mature and older stages of the cycle. The second is based on the fixity of the baselevel surface in contrast to the variation in the slope of graded rivers. The third springs from the essential simplicity

in the meaning of "baselevel," in contrast to the complexity and variety of conditions ultimately gathered under the term "grade."

Baselevel is complete from the beginning, and permanent to the end; Grade is slowly introduced and gradually extended.—The conception of the general baselevel must be made at the outset as that of a completed surface extending beneath the land mass under consideration at the beginning of the cycle, and so remaining as long as the advance of the cycle continues undisturbed. In the ideal case, which provides the general scheme with respect to which all other cases are classified, the land mass once uplifted is supposed to stand still until it is worn down flat. This supposition is so artificial, and does so great violence to much that is known as to the behavior of the earth's crust, that some students are therefore disposed to discard the scheme of the cycle altogether in the study of the sculpture of land masses, overlooking the fact that however many movements of a land mass may be discovered, the many incomplete cycles that are separated by these movements must each be treated essentially according to the scheme of the ideal cycle. In every case, the processes of land sculpture, quickened or slackened in consequence of the new attitude given to the region, go on with respect to the new attitude of the baselevel within the land mass.

Even during the movement of the land mass, it must be conceived of as rising or sinking through a fixed and complete baselevel surface, with respect to which its carving is even then begun, and long afterwards continued, during the ensuing time of relative or absolute rest. Hence, for every cycle or partial cycle of erosion, the imaginary baselevel surface is immediately conceived as complete at the outset, and as thenceforwards remaining unchanged. Local baselevels are also complete, in extending at once as far as the imagination wishes to carry them; they rise or fall slowly with their control.

It is far otherwise with the development of the graded condition. The previous paragraphs have explained that the devel-

opment of grade depends on the spontaneous adjustment of the capacity of a river to do work, and the quantity of work to be done by the river. It is well understood that this adjustment is realized by the larger streams relatively early in the cycle; by those of medium and smaller size at later and later stages; and hence that the condition of grade is deliberately introduced and systematically extended through all parts of a river system as the cycle advances. The condition of grade needs no mention when the scheme of the cycle is first presented. Truly, it might be considered as an accompaniment of the youth of a cycle in those special cases where a large river is running across a slowly rising region of weak rocks, for here the condition of grade may be continuously maintained during the period of uplift. But it is not in connection with special cases of this kind that a first acquaintance with the condition of grade is best made. Its fuller meaning is not likely to be well understood unless presented with something of the deliberation that characterizes the actual development of graded rivers. Indeed the conception of grade is likely to be an embarrassment if presented too early.

The extension of the graded condition over all parts of a river system introduces a thoroughness of organization in the processes of land sculpture that warrants the use of the term "maturity," as the name of the stage of the cycle in which the organization of river systems is chiefly accomplished. The growth of organization goes with the development of grade. In every reach of a river in which the graded condition has been attained, the lowest point on the reach is always coincident with and dependent on a controlling baselevel (as above defined) either general or local, and river action at any point in the graded reach is then delicately correlated with that at every other point. River action in such a reach may justly be said to be organized, inasmuch as a change in form or action at any one point involves a change at every other point. Adjacent reaches, separated by a fall on an ungraded ledge or by an unfilled lake, are independently organized; a change

in one does not necessarily call for a change in the other. But when all falls and rapids are worn down, and all lakes are filled up, and the entire river system is graded, as is characteristically the case in the late-mature stage of a cycle, the organization of the system is so complete that all its parts are correlated. A change at any one point then involves a change, of infinitesimal amount perhaps, all through the system. It is this condition of organization that Gilbert alluded to in describing the "interdependence" that comes to be developed among the different lines of a river system, as a result of which "a disturbance upon any line is communicated through it to the main line and thence to every tributary"—(1877, 124).

The actual slopes of the different parts of a graded river system vary from a faintest declivity in the lower course of the trunk river to decidedly steeper declivities in the uppermost courses of the headwater streams. If any stream line is followed from head to mouth its profile will show a curve, approximating theoretically to the flatter part of one wing of a parabola;[1] but when studied in detail, the normally continuous decrease of slope down stream is found to be seldom realized. The entrance of a tributary is usually accompanied by a decrease of slope up-stream and an increase of slope down-stream from the tributary mouth; the spasmodic action of floods introduces some faint symptoms of disorder in otherwise simple slopes; and in this connection the inequalities due to what McGee has called "varigradation" are to be considered (1891, 269; see also Oldham, 1888). All these complications in the slopes of a graded river system make it extremely difficult to conceive of a surface which shall generalize the river slopes. Indeed, it is hardly worth while to attempt this conception, for the reason that all the value of the imaginary surface is to be found in the actual slope lines of the graded river systems by which the surface is guided. It is with respect to the sloping course of a graded stream that the valley

[1] It is evidently only under the assumption that the baselevel is not a convex level surface, but a plane that the profile of a river can be described as a parabola. The actual profile of a large river, such as the Mississippi, is convex to the sky.

sides are to be worn down; it is with respect to the graded lines of a river system that its whole basin is to be worn down. This conception, as announced by Powell, is of fundamental importance; but it does not seem to gain in clearness or strength by expressing the control of erosion in terms of a warped surface, guided by the branching lines of the graded river system, instead of expressing it distinctly in terms of the branching stream lines themselves. Reference will be made again to this aspect of the problem further on.

Not only do graded streams vary in slope in different parts of a river system; the slopes may vary greatly in two neighboring river systems at the time of the general establishment of their grade. This may be illustrated by considering the unlike conditions obtaining in two rivers, alike in volume, but one flowing through an upland of resistant rocks, the other through a similar upland of weak rocks. The first would have to cut down a deep valley to a gentle slope before grade was reached; because its load would be slowly delivered from the resistant rocks of its valley walls, and high walls would have to be produced by deep valley cutting before a balance could be struck between the increasing load from the walls and headwaters and the decreasing capacity of the river. The second river could not cut so deep a valley, however weak the rocks of its bed, because it would have an abundant load supplied by the rapid wasting of its valley sides, even when they were of moderate height, and a strong slope down the valley would be required in order to maintain a velocity with which the graded stream could bear the abundant load away. Only as the whole upland is worn down in the later stages of the cycle could the second stream wear down its valley to a gentle slope; and then the valley would be still shallower than when grade was first attained.

The principle here considered is clearly recognized by Gilbert, who instances the Platte as a river of the second kind, and states that Powell also had so described it (1876, 100). The difference between the two kinds of rivers is not satisfactorily indicated in terms of baselevel; but it is clearly presented by

stating that one has developed its grade on a faint slope, the other on a stronger slope.

The incapacity of the Platte to deepen its valley leads Gannett to describe it as an "overloaded river(1900); but this phrase is not altogether satisfactory, because it overlooks the fact that rivers refuse to be overloaded. A river will most dutifully work up to its full capacity; it is ready to increase its capacity by increasing its slope through aggrading when necessary (as stated below), and thus it may become heavily loaded; but like the traditional llama it refuses to carry an overload. Like all streams with braided channels, the Platte is well graded, as well graded as the typical lower Missouri, although the quantity and texture of its load require it to maintain a relatively strong slope.

Baselevel remains fixed all through an uninterrupted cycle : the slope of graded streams must vary as the cycle advances.— After a river system has attained a maturely graded condition, it will maintain a graded condition through all the rest of the undisturbed cycle; but it is important to recognize that the maintenance of grade, during the very slow changes in volume and load that accompany the advance of the cycle, involves an appropriate change of slope as well. Instead, therefore, of having to do with a fixed control of erosion, such as is found in the general baselevel of a region, we have here to do with a slowly, delicately and elaborately changing equilibrium of river action, accompanied by a corresponding change in river slope. For example, a large river in a mountain valley may reach grade in the early maturity of its region. It will then flow with a rushing current on a rapidly sloping bed of cobblestones; and it may stand hundreds or even thousands of feet above baselevel. In the old age of the region, the same river will flow with a sluggish current on a nearly level bed of sand and silt through a peneplain, only a few tens or scores of feet above baselevel.

This is a point that is not generally enough recognized. It is too often implied — in the absence of explicit statement to the contrary — that when a river is once balanced between

erosion and deposition its slope thenceforward remains constant. The beginner would gather this understanding of the question from several of the definitions of "baselevel" above quoted, but such is evidently not the case. When a stream is first graded, its channel is not level, and it has not reached the base of its erosive work. In virtue of the continual, though slow, variations of stream volume and load through the normal cycle, the balanced condition of any stream can be maintained only by an equally continuous, though small, change of river slope, whereby capacity to do work and work to be done shall always be kept equal. It might at first be thought that changes of this kind would be perceptible, and that there would be occasional departures of a river from the graded condition; but such is not the case, because the change in the value of any variable in a unit of time is only by a quantity of the second order, by a differential of its total value. Once graded, a river will never depart perceptibly from the graded condition as long as the normal advance of the cycle is undisturbed. The slope of a river must necessarily be steeper on the first attainment of grade in early maturity, when an abundant load is received from the steep valley sides and the active headwater, than in late old age, when the valley sides have been worn down almost level, and when the even headwater streams are weak and sluggish. Hence, just as a graded river has slopes of varying declivities in its different parts at any one time, so the slope at any one part of the river must vary at different times in the successive stages of the cycle.

Not only so: it is eminently possible that the slope of a graded stream may have to be increased for a time after it has been first attained, for there is no necessity that the load should cease increasing just when its value has risen to equality with that which the stream can transport. There is much probability that, after grade is reached in a normal, undisturbed cycle, a river may have for a time to aggrade its valley floor until the time of maximum load is reached: and only after the maximum gives way to a decrease of load can there be a beginning

of that very slow and long-continued decrease of river slope which continues through late maturity and old age. Furthermore, if at any time in the cycle a change of climate should occur, new slopes would have to be developed by the streams in order to bring about a new balance between erosion and transportation under the new relation of load and volume. If, for example, the changes were from humid to arid conditions, all the valley floors would have to be steepened by aggradation. If from arid to humid, the graded valley floors would be sharply trenched, and in time reduced to lower slopes. There can be little doubt that under an increased rainfall the "baselevel" described in southeastern California by Fairbanks would be sharply dissected, quite independent of any elevation of the region. I have already discussed certain aspects of this problem (1896, 377).

The clearest account that I have found of the normal variation of the graded slope is in the paper by Johnson already cited. He says that the graded slope "continually alters its inclination. There is a slow departure from equilibrium, and there is closely following readjustment toward recovery of it." The graded slope passes through its "transformations with a slowness comparable to that of mountain wear. . . . . It keeps pace with the slow growth of the débris mass following upon mountain lowering." But, if a stream be deprived of the greater part of its load by some abnormal changes, it "would at once attack its former slope of equilibrium, and rapidly, though at a progressively slowing rate, lower it. On the other hand, its load largely increased, the stream would rapidly build up the slope. In either case, however, it would come to a stand at a new grade of equilibrium" (1901, 621).

The same author attaches much importance to the effect of climatic changes on graded river slopes. When describing the dissection of the High plains, he says:

> It is not necessary, in order to account for change in behavior of the traversing streams, to appeal to deformation. A sufficient cause may be looked for in change of climate. There is record of erosion, with reversal to deposition and rebuilding, and reversal again finally to erosion, and there is reason

for believing that this series of interruptions of the gradation cycle was an effect of climatic oscillation rather than of earth movement (1901, 628).

This is by far the most striking actual example of varying graded slopes on record: an example that is easily defined in terms of changing grade, but not in terms of changing baselevel. It is much more satisfactory to describe the High plains in terms of stronger or fainter graded slopes than to consider them "near baselevel," as has been done in spite of their standing at altitudes of 4,000 feet and more.

The conception of grade must therefore include the conception of different and changing slopes in large and small streams, in mature and old streams, in streams dissecting weak and strong rocks, in streams of arid and humid regions. The conception is of the greatest value as a supplement to the simpler idea of baselevel; but it is so intricate that it cannot be fully apprehended until the whole course of the cycle is patiently worked through. Yet a still further extension of the conception remains to be considered.

Baselevels are of only two kinds, general (permanent) and local (temporary); Grade includes not only the balanced condition of large and small, mature and old water-streams, but that of all kinds of waste streams as well.—A final reason for giving different names to the limiting base of subaerial erosion and to the balanced condition of the mature and old streams that are working with respect to the limiting base is found in the essential identity of conditions in graded water streams and in graded waste streams, and in the strong unlikeness between the attitude of a baselevel surface as defined in any of the above citations and the slopes often assumed by graded waste streams. These are points to which the geologists and geographers of the older schools gave little or no attention: indeed it is only about fifty years since some of the leaders of our science taught that rounded hills could not be formed by subaerial erosion and that they must be the work of the sea. It is now well understood, however, that slopes covered with soil of local or up-hill derivation are really "drained" by an association of many graded waste

streams, whose behavior closely resembles that of graded water streams.

The first development of the balanced or graded condition in waste streams usually takes place on the outcrops of the weaker rocks that are exposed on freshly cut valley sides. Here graded waste slopes are locally developed; the adjoining waste streams form a sheet or cloak of waste which creeps slowly down the slope, while untamed ledges of harder rocks are still kept bare by the removal of waste from their surface as fast as it is formed. These represent the falls and rapids of water streams, because the waste from above the ledges passes over them quickly; while the graded waste-covered slopes represent the graded reaches of water streams, where the movement is more regular and leisurely. The less resistant of the bare ledges are the first to retreat under cover, permitting the grades below and above to unite in a single continuous slope; and so on, until all ledges are concealed under a graded sheet of waste, and the sharp, vigorous forms of youth and early maturity merge into the subdued and tamed forms of passing maturity and approaching old age.[1] During the progress of this change, there may be abundant examples of captures of one group of waste streams by the leading members of another group, especially in regions of tilted strata; thus increasing the resemblance of waste streams and water streams, until one is tempted to regard the difference between them as one of degree rather than of kind.

As maturity passes into old age all the elevations are worn lower and lower and the graded cloak of waste covers more and more of the surface. As the later stages of the cycle are approached, the whole region, monadnocks excepted, is reduced to moderate relief and bare ledges are rarely seen. On the faintly sloping forms of advanced old age the graded sheet of waste covers the entire surface between the water streams. Everywhere gently waste-covered slopes lead from the low

[1] I have pursued the comparison of water streams and waste streams somewhat further in my paper on "An Excursion to the Grand Canyon of the Colorado (1901, 176).

arched divides to the streams. The surface soil, greatly refined in texture by long exposure to the weather in its deliberate journey slowly creeps and washes to the streams, and the relief is reduced to smaller and smaller measures. The condition of grade, at first developed in the lower course of the larger rivers, next in their branches and headwaters, then on the valley sides and over the hills, has thus been extended all over the region. The organization that at maturity characterized the water streams has come in old age to characterize the streams and sheets of waste all over the land surface. From the beginning to the end of this process, there is steady progress without break or interruption through the normal cycle. There is an essential unity of development through the whole of it. It is very desirable that this unity should be expressed in the terms employed in the description of land sculpture and land form; and that the balanced condition of water streams and waste streams alike should be expressed by such a term as grade, rather than that an artificial distinction between them should be introduced by speaking of the balanced rivers as defining a "baselevel," while balanced waste streams are given some other name by which their close affinity to graded water stream is concealed.

An old land surface, sheeted over with a graded soil cover, is a peneplain of erosion or of gradation; it passes slowly into a plain of gradation. It is almost the realization of that imaginary baselevel surface described by Powell as "inclining slightly in all its parts toward the lower end of the principal streams draining the area through which the level is supposed to extend, or having the inclination of its parts varied in direction as determined by tributary streams;" but this imaginary surface is elusive and intangible, because of the impossibility of defining the stage of stream development when it should be introduced, and the length of graded stream course that it should follow; while on the other hand the graded land surface is a reality whose gradual development and slow change is one of its essential characteristics.

Until the imaginary surface is thus realized, it is hardly worth while to attempt to conceive it; for as far as the control of erosive processes is concerned, that is better exercised (as has been stated already) by the visible skeleton of the surface that is seen in graded streams than by the surface itself. It is always with reference to the graded course of the main river that the side streams are graded; it is with reference to all the graded streams that the slopes of the interfluves are graded. These relations of branch to trunk and of side slopes to streams are of the very greatest importance and must be considered with the utmost care; but the imaginary surface passing from river to river under the hills of the interfluves has relatively little importance as a control of the processes of erosion. With every extension headwards along the graded channels of branching streams, the surface becomes more warped and wrinkled, more difficult to conceive, more likely to differ as conceived by different minds. It must be not only irregularly warped when first defined, but it must vary slowly in form and slope. Just as no limit can be set to the headward part of the graded main stream or to the number of graded branch streams to be taken as guides for the imaginary warped "baselevel," so no limit can be set between the graded stream courses and the graded waste slopes of their head or along their sides. The imaginary surface should, if conceived at all, follow the lead of *all* the graded lines and surfaces as fast as they are developed; it should be extended as they are extended, modified as they are modified. But if this be agreed to, part of the imaginary surface becomes a real surface, and the rest may be neglected until it also is realized.

Just as every reach in a stream is graded with respect to the next down-stream barrier or local baselevel, so every waste slope is graded with respect to the ledge or cliff at its lower margin; the lowest reach, ending at the river mouth, is graded with reference to the general baselevel or the ocean; the lowest graded slope of a valley side is graded with reference to the stream (or flood plain) in the valley bottom. Again, every bare ledge on a mountain side will, in time, be graded (or consumed) by the

headward growth of the graded slope next below it, just as every ledge of rocks that makes a fall or rapid at the head of a reach will, in time, be obliterated by the up-stream extension of the graded reach. (In both cases, when the time of extinction of the ledge is attained, the waste slope and the stream reach will probably have been worn somewhat farther into the land-mass, assuming a somewhat fainter declivity—that is, coming closer to baselevel—than was the case while the ledge still existed.)

The close similarity, the real homology between the two classes of streams, makes it all the clearer that "baselevel" is not a good term to apply to either. It is not desirable to say that a hillside ledge is "baseleveled" when it is worn back so far that it disappears under the slope of the growing sheet of waste; yet it is certainly desirable to indicate by the use of an appropriate terminology that the disappearance of the ledge has been accomplished by changes of the same kind as those which have caused the obliteration of falls and rapids in rivers. Hence it seems desirable to say that every ledge, in valley side or stream bed, will in time be graded—not baseleveled—with respect to the attitude assumed at that future time by the graded—not baseleveled—reach or slope next below it.

It is, perhaps, on account of the elusive character of the imaginary warped surface that its definition is sometimes couched in indefinite language. In the original definition, Powell said:

> I take some liberty in using the term level in this connection, as the action of a stream in wearing its channel ceases, for all practical purposes, before its bed has quite reached the level of the lower end of the stream. What I have called the baselevel would, in fact, be an imaginary surface, inclining slightly (1875, 204).

In a later paper he said again:

> It will be understood that the land plain which is brought down to the level of the sea has its margin on the seashore, and that it extends back from the shore a distance which may be miles or hundreds of miles. As it stretches back, its surface rises slightly. The whole plain is not

brought down absolutely to the level of the sea, but only nearly to that level (1895, 34, 35).

Salisbury states that "no definite degree of slope can be fixed upon as marking a baselevel." Geikie defines baselevel as "a level not much above that of the sea." Brigham writes:

The great river first cuts its bed close to the sea level, and we say that a portion of the valley is reduced to baselevel. It lacks a little of it, but the difference is so small that we neglect it.

These qualified statements are apparently the result of attempting to define a surface in terms of its variable feature, slope, instead of in terms of its constant feature, balance of activities. Whatever slope is agreed upon must change to a fainter slope if more time is allowed; but the balance, once struck, is always maintained as long as the cycle endures. Another cause of difficulty in definition seems to have arisen from giving the same name to a variable and to its limit. Both the imaginary warped surface and the actual peneplain are essentially variables; their variations are similar and systematic; they both approach, but never reach the limiting base of subaerial erosion. The latter is essentially a constant, accurately definable from the beginning, and remaining unchanged while the variable surfaces approach it. It may be defined as the limit of either of these variables in a strictly mathematical fashion. The baselevel is the level base toward which the land surface constantly approaches in accordance with the laws of degradation, but which it can never reach.

Plains and peneplains.— The names for surfaces of ultimate and penultimate subaerial erosion deserve brief consideration. My own preference, prejudiced, perhaps, by a share that I have had in making up names, would be to avoid "baselevel" as a technical name for any geographical form, to use "plain" sparingly for surfaces of erosion, because of the rare occurrence of complete or ultimate planation; and usually to employ "peneplain" as the name for the penultimate form developed in a cycle of erosion. It was in order to avoid the implication of complete erosion, and the objections

that such an implication aroused, that the term peneplain was suggested thirteen years ago. This word gradually came into use with quotation marks and an explanatory footnote. The footnote disappeared first, and now the quotation marks are frequently omitted as if the word had gained an established position, although among writers in Great Britain the need of the term is still so little felt that it is generally mentioned as an American invention when used at all, instead of being fully adopted, like delta and atoll, without explanation or acknowledgment.

There seems to be today less hesitation regarding the acceptance of the idea of far-advanced subaerial degradation than there was fifteen years ago — witness the use of "plain of erosion" by Hobbs (137) as a name for the worn-down surface, now uplifted and dissected in the uplands of Connecticut; nevertheless it still seems desirable to speak of such surfaces as peneplains in the absence of proof that they were actually reduced to plains. The alternatives for peneplain are as follows:

Powell contrasts "gradation or true plains" with "diastrophic plains" (plateaus), the former being produced by gradation, a "process accomplished through the agency of water," and the latter by the uplifting of the earth's crust. This use of "gradation" is a natural complement of the use of "grade" in the sense advocated in this essay. Gradation plains are then treated under four heads: sea plains, lake plains, stream plains, and flood plains. Of the first class it is said:

> Whenever in any region the process of slow upheaval comes to an end, and such district is still subject to degradation by rains and streams, the process of reduction goes on until the surface is brought down to the level of the sea . . . . The sea-level plain is permanent in the absence of diastrophism. . . . Low lands with surfaces more inclined, and with more swiftly running streams, are still called *plains* though they are not fully brought down to baselevel; sometimes they are, called *peneplains* (1895, 34, 35).

Sea plain has not come into general use, perhaps because of possible confusion with sea-cut plains, or plains of marine denudation. The following extract gives an example of the

employment of the term with double meaning by Hughes, in describing the uplands of western Yorkshire:

> It is to both of the agencies above mentioned [marine and subaerial erosion], acting simultaneously throughout long ages, that we must refer the tremendous results that we have forced upon our attention . . . . We will refer to these great plateaux by the shorter term sea-plain; to distinguish them from the river-plains or bed-plains (131).

Dryer uses the phrase, "graded plain," in a somewhat different sense. The reduction of the border of a land area to a submarine plain by sea action, while the rest of the land surface is reduced to "baselevel" by subaerial processes, would result in the production of a "graded plain, lying partly above and partly below sea level" (234). No example of this kind of plain is mentioned. Gradation plain is used by Adams for a locally developed peneplain between residual ridges (508).

The terminology employed by Hayes departs somewhat from that in use with other writers. He says:

> The processes which tend to produce a baselevel plain are embraced under the term *gradation*. This includes aggradation and degradation. . . . . A *baseleveled surface* is any land surface, however small, which has been brought approximately to a baselevel, either general or local, by the processes of gradation. When such a surface has considerable extent it becomes a *baselevel plain*. . . . . The term *baselevel peneplain* or simply *peneplain* is applied to a surface of which a greater or less proportion has been reduced to the condition of a baselevel plain, but which contains also some unreduced residual areas (21, 22).

It seems to me that it is going too far to say that "a baselevel surface is any land surface, however small, which has been brought approximately to a baselevel, either general or local." It would follow from this definition that, inasmuch as every point in a continuously graded river is a local baselevel for every other point further up-stream, the upper stretches of the flood plain or broad valley floor of a large river would be called a baselevel surface, in spite of their standing several hundreds or even thousands of feet above the general baselevel. The valley plain of the Platte, for example, attains altitudes of more than 3,000 feet, and cannot be fitly described as a baselevel plain, unless baselevel is

taken to mean a sloping surface. It may be more appropriately called a graded valley plain, or a graded valley floor, for these terms do not contain any implication that the surface is either low or level.

Another objection to the above use of "baseleveled surface" is that it arbitrarily separates graded valley floors and graded hill sides, whose analogies with respect to the processes of gradation ought to be exhibited rather than concealed in a systematic terminology. It can hardly be supposed that anyone would today call a waste-covered hillside a "baseleveled surface," although it has every characteristic with respect to the processes of gradation that is possessed by a graded valley floor. A third objection to this use of "baseleveled surface" would be found when applying it to the High plains of eastern Colorado and western Kansas, which, according to the explanation offered by Johnson and cited above, were produced by aggradation during a time of less rainfall than at present. Here an extended surface was, as Hayes might phrase it, "brought approximately to a baselevel, either general or local, by the processes of gradation," and yet it was actually built up hundreds of feet above the pre-existent and the present valleys, and thousands of feet above the general baselevel, although there is no indication of any discontinuity in the graded surface between the High plains and the mouths of their aggrading rivers. The High plains are better called aggraded river-made plains, or *fluviatile plains;* and in this respect they resembled the great plains of northern India.

The geographical cycle.—The period of time during which an uplifted land mass undergoes its transformations by the processes of land sculpture, ending in a low featureless plain, has been called a geographical cycle, or, as Lawson phrases it, a "geomorphic cycle" (253). Hayes writes: "The term *gradation period* is employed for the entire time during which the baselevel remains in one position; that is, the interval between two elevations of the earth's surface of sufficient magnitude to produce a marked change in the position of sea level" (22),

but on later pages he uses the phrase "cycles of gradation" or simply "cycles" instead of "gradation periods." It matters little which of these terms is used; but it would certainly be an advantage that only one should be retained to express the single idea here considered.

Denudation and degradation.— It seems worth while to call attention in this connection to the desirability of a more careful discrimination than is customary between the terms, denudation and degradation. Denudation might be advisedly used as the name of those active processes, chiefly operative in the youth and maturity of a cycle, by which rock structures are laid bare, literally denuded, because their waste is removed as fast as it is formed. Degradation on the other hand is more appropriately associated with those liesurely processes, characteristic of the later stages of the cycle, in which a graded slope is reduced to fainter and fainter declivity, although maintaining its graded condition all the while. Aggradation is naturally the opposite of degradation, and implies the deposition of rock waste by transporting agencies, the built-up surface being always kept essentially at grade. Thus defined, denudation would accompany the early work of downward corrasion by streams, and the longer-lasting work of valley widening by weathering and washing. It would be systematically transmuted into degradation as the processes that operate on the various lines of down-slope streaming attained the graded condition; the large rivers first, the smaller branch streams later; the headwater streamlets and the hillside waste streams later still. Retreating cliffs and summit ledges, the last strongholds of denudation, would pass into the phase of degradation when they are reduced under the graded waste cover in the stage of subdued relief, characteristic of late maturity and early old age; and thenceforward all further erosion would be by degradation alone.

Conclusion.—It may seem at first reading that this essay is concerned with words rather than with facts; but such is not my intention. My object has been primarily to secure a just and accurate recognition of facts, and only secondarily to attach

words to the facts as convenient handles by which to bring the facts forward. It is a fact of large import that the wearing down of land masses proceeds in an orderly manner, involving the disclosure of bare rock ledges (denudation) in the earlier stages of the cycle of erosion, and the concealment of all ledges under a graded sheet of waste in the later stages of the cycle (degradation). It is a fact of much delicacy that streams tend to assume a balanced condition as to corrasion and transportation; that after once attaining this condition they preserve it as long as their work continues without disturbance; but that the slope of their graded courses must vary systematically through the stages of maturity and old age, as well as through changes of climate. It is a fact of great value in geographical description that the balanced condition of water streams is imitated so closely by that of waste streams that one set of terms applies to both kinds of streams.

There can be no question that the adoption of a suitable term as the name for a fact is a great aid to the general recognition of the fact itself. It is largely on this account, as well as in the interests of a precise terminology, that I have here written out a series of notes that have been gathered during the past two years, and of which some account was given at the meeting of the Geological Society of America in Washington, in December, 1899.

It is admittedly difficult always to use terms in a manner that is perfectly consistent with their definitions. It is rarely possible to limit terms to a single meaning. It is probable that in this attempt to reduce our terminology to greater simplicity and better order than now prevails I have laid myself open to criticism on the very grounds that are objected to in the course of this essay. Further discussion may therefore be advisedly directed to a settlement of open questions. It is certainly open to consideration whether "denudation" and "degradation" should be limited as above suggested; but the advisability of holding "baselevel" and "grade" to the meanings here indicated seems to me much less open to difference of opinion. The future

meanings of these words will depend much less on the preference of the older geologists and geographers of today than on that of their younger successors. I therefore urge those who are now taking up the use of such terms as baselevel and grade, denudation and degradation, to consider carefully the meaning to be adopted for them.

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EDITORIAL.

PROFESSOR A. B. WILLMOTT, in a paper upon "The Nomenclature of the Lake Superior Formations," found in the present number of this JOURNAL, proposes several radical changes from the succession as held by those who have for many years laboriously studied this region. At the present time I shall not discuss Professor Willmott's proposals. I merely wish to state that the evidence presented for them appears to me wholly inadequate, and I therefore record my dissent. At a later time I shall take up the modifications of the nomenclature of the Lake Superior Region which seem to me to follow from the recent work of the officers of the United States Geological Survey.

C. R. V.

A NEW edition of No. 1, Vol. I, of the JOURNAL OF GEOLOGY, has been published, and complete sets of the JOURNAL can now be furnished at the regular subscription price.

C.

Reviews.

Influence of Country Rock on Mineral Veins. By Walter Harvey Weed, United States Geological Survey, from the transactions of the American Institute of Mining Engineers, Mexican meeting, 1901.

Abundant evidence is brought forth and satisfactorily stated in this paper to show three things: that the structural characters of vein fissures are affected by the country rock; that the mineral contents of ore deposits formed by metasomatic replacement vary with the nature of the enclosing rock; that no invariable relation can be established between rock types and ore deposits. Variation in structure of the fissure naturally, though not invariably, follows a change in texture, cleavage, and hardness of the rock through which it passes. In rocks which are fissile or easily fractured, fissures often lose their definite character and ramify the rock through which they pass, so that the ores which they carry lose their economic significance. In passing from soft to hard rock mineral veins are apt to grow narrow, and are often deflected. Regardless of the origin of the ore, there seems to be a connection between the nature of the mineral deposit and the country rock, where the mineral deposit is of the nature of a replacement. No such connection appears in the filling of open fissures. On account of differences in chemical constitution of the ore-forming solutions, the chemical reactions which took place in the process of vein forming in a rock of a given kind in different districts, were necessarily different, resulting in a variety of ore deposits. Within a limited district, however, the nature of the ore forming solutions was often very constant, and there is a uniform variation in vein content, with variations in the wall rock.

These generalizations are supported by an interesting body of evidence drawn from the literature on ore deposits, both American and German, and from the writer's personal observations. The principles deduced are moderate, and are for this reason all the more acceptable. They are an advance on anything that has been attempted along this line, and have both theoretical and practical value.

Frank A. Wilder.

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